918

THINGS TO COME

Mir Publishers

Moscow

ИЗДАТЕЛЬСТВО • МИР •

«Заглянем в будущее»

Сборник статей

Издательство ЦК ВЛКСМ
«Молодая гвардия»

THINGS TO COME

Collected Articles

Mir Publishers · Moscow

Composed by V. FEDCHENKO

На английском языке

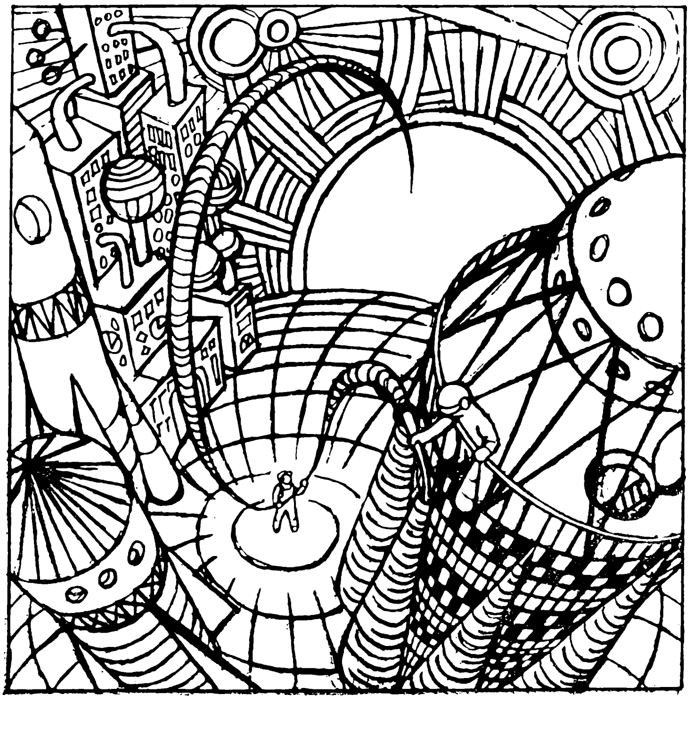
First published 1977
Revised from the 1974
Russian edition

CONTENTS

A STORY OF
POWER RESOURCES OF THE FUTURE
AS TOLD BY

ACADEMICIAN

N. N. SEMENOV



Modern science and technology offer vast opportunities of fully satisfying the main material needs of all the Earth's population. That this noble aim has not been achieved as yet is due largely to social factors, such as inadequate organization of human society, rather than to the lack of scientific and technological knowledge or shortage of manpower and material resources.

Of primary importance in laying the material foundation of society and bettering the life of man are the available power resources of the world and, especially, the available output of electrical energy per capita. The world average output of electrical energy per capita stands presently at about 0.23 installed kilowatt, an extremely low figure in view of the fact that it is many times lower in the developing countries of the world.

Electrical energy is by far the most versatile and useful form of energy. In our days it is generated for the most part at thermal electric power stations burning all kinds of fuel. In many cases, however, the thermal energy obtained by burning fuel is used directly, as, say, in the case of car and aircraft engines. Therefore, the available power per capita is determined in the final analysis by the amount of fuel available per capita. Estimates give a world average of about 2 tons of reference fuel per capita, i.e., of fuel having a heating value of 7,000 kcal/kg. Naturally, the figure varies widely for different countries. In the United States, for instance, it is equal to 10 tons of fuel per capita, whereas India has only 0.2 ton per capita, i.e., 50 times less.

Let's begin with a glance at the state of affairs in the power industry of our days that relies for its operation mostly on the combustion of fuel minerals (coal, oil and gas). At present, about 6 billion tons

of reference fuel is extracted in the world annually. This fuel liberates 7×10^6 kcal/ton upon combustion and, consequently, yields a total energy of 42×10^{15} kcal. The table presented below gives a general idea of the consumption of fuel in different fields, the data being expressed as a percentage of the total amount of extracted fuel.

Transport (motor, air, railway, water) and agricultural machines (mainly tractors)	20 to 25%
Thermal power stations, including central heating-and-power plants (to date)	30 to 35%
Industry, in particular the metallurgical, chemical, machine-building and construction material branches of industry	30%
Public utilities	5 to 10%

The electrical energy produced by thermal power stations accounts for 30 per cent of the total amount of fuel extracted in the world. And it should be noted in passing that while these power stations are the most predominant, they generally have an average efficiency not higher than 30 per cent. Hydroelectric power stations produce about 17 per cent of the total output of electrical energy, and nuclear power plants so far do not contribute significantly to the world energy balance.

The extremely high rate of industrial development and agricultural mechanization, as well as the rapid increase in the Earth's population, cause an ever greater consumption of fuel minerals. Under the circumstances, with such a rising demand it's only natural to wonder how much longer the world wealth of fuel will last. This is rather a difficult question to answer since there are as yet no sufficiently reliable theoretical grounds for making even an approximate estimate of the capacity of known fuel resources. The figure for explored world reserves is seen to vary from year to

year. Over the last thirty years, for instance, geologists have discovered an immense wealth of oil in various parts of the world, whereas the old long-established oil fields are becoming practically exhausted.

Tentative estimates of profitable world resources of fuel minerals have nevertheless been made on the strength of the capacity of known deposits and geological forecasts. Data pertaining to one of those estimates is listed in the following table.

Fuel	Fuel resources		Accessible resources	
	tons	%	tons	%
Total	12.394×10^{12}	100	3.484×10^{12}	100
Coal	11.240×10^{12}	90.44	2.880×10^{12}	82.66
Oil	0.743×10^{12}	6	0.372×10^{12}	10.68
Gas	0.229×10^{12}	1.85	0.178×10^{12}	5.11

The second column of the table contains a list of present-day geological forecasts, while the fourth column presents data on accessible deposits, the extraction of which is economically justified.

In 1970, the world output of fuel indicated in the table was in the neighbourhood of 6 billion tons of reference fuel. This means that the annual output of fuel throughout the world amounted at that time to only 0.15 per cent of the available resources listed in the fourth column of the table.

The world output of fuel increased at quite a high rate over the last few decades and practically doubled every twenty years.

Proceeding from the rate of fuel output recorded in those years and assuming it to remain at the same

level in ensueing years make it possible to estimate the annual output to be expected in the near future mathematically. Let $A=6\times10^9$ tons of reference fuel represent the world output of fuel minerals for 1970, and let t years be counted from that date. Hence, the annual output of fuel minerals in the coming years will be $Q=A\times2^{t/20}$. What we seek, however, is the total output of fuel over the years following 1970, rather than the annual output.

Let us draw up the following table to see what part of the available resources (listed in the fourth column of the preceding table) will be extracted in the course of t years.

t, years	Year	$2^{t/20}-1$	$30A\,(2^{t/20}-1)$, tons	Output in t years, in per cent of available resources
20	1990	1	18×10^{10}	5.14
40	2010	3	54×10^{10}	15.4
60	2030	7	126×10^{10}	36.0
80	2050	15	270×10^{10}	77.0

The conclusion to be drawn from the above estimate is that the world fuel resources will practically become fully exhausted within the next 80 years.

Should further prospecting and higher efficiency of extraction bring about, say, an 8-fold increase in fuel resources (a greater increase can hardly be expected as deep drilling has long been practiced), even then the world fuel resources would be exhausted by 2110 instead of 2050, i.e., within 140 years instead of 80 years.

Forecasts made by American scientists have yielded similar results. According to one of their estimates, the economically feasible fuel resources of the United States will be exhausted in the course of 75 to 100 years, and the total potential reserves of fuel will run out in 150 to 200 years.

That the rate of fuel extraction has increased so greatly over the last few years is quite understandable. The point is that the world output of oil has increased enormously from 1880 to our days; it practically doubled every ten years. During the first thirty years of the 20th century, the world output of oil was rather low as compared with that of coal. In further years, the output of oil increased significantly and by 1950 became equal to half the coal output (in terms of reference fuel).

The share of oil and gas in the output of contemporary fuel has risen sharply over the last ten years and now accounts for about 70 per cent of the total output of fuel, whereas the share of coal has dropped to 30 per cent. And yet—as is evident from the table—the world resources of oil and gas are over five times smaller than those of coal. Should oil and gas continue to be spent in future at the present rate, the resources of this raw material so greatly needed in transport and the chemical industry are likely to be exhausted within the lifetime of today's generation of young people. It follows that the world output of electrical energy should be based mainly on the consumption of coal.

There are many scientists who doubt that the world output of fuel will continue to increase at the present rate in future and hold the opinion that it will eventually start to drop. To me, this does not seem to be true. A specific feature of the 21st century will most likely be the rapid technological progress of the deve-

loping countries. We have already seen that there is a great disproportion in the output of fuel per capita. 50 times more fuel minerals is consumed in the United States per capita than in India. The state of affairs will change radically in about 100 to 150 years, and the output of fuel in the various groups of countries will at least approach the highest level if not become equal among them. Therefore, it is more likely that fuel will be extracted at a higher rather than a lower rate on a world scale.

All these forecasts are based on different assumptions and are liable to vary, of course, within a wide range. What is quite clear, however, is that the available resources of fuel minerals will in any case run out within the foreseeable future. Mankind is actually on the eve of a catastrophic shortage of energy. We are at present carelessly squandering most precious resources that future generations will need badly to produce chemicals, organic materials, detergents and so forth. Therefore, the immediate task—confronting, primarily, scientists and engineers—is to discover new and more efficient means of meeting mankind's ever growing energy requirements. And this problem must be solved as quickly as possible while there are still sufficient amounts of fuel minerals in reserve for the chemical industry for the next hundred years. Fortunately, over the last twenty years certain moves have already been made in this direction.

There are also other reasons, besides that of rapidly diminishing resources why it is essential to switch over to new kinds of energy other than fuel-generated energy.

The combustion of fuel in modern factories, electric power stations and internal combustion engines leads to the expulsion of enormous amounts of carbon dioxide into the atmosphere. Fuel minerals have been

burnt over the last ten years in an ever increasing quantity in the combustion chambers of engines and the fireboxes of boilers. As a result, an additional enormous amount of carbon dioxide is assimilated by plants and, also, absorbed by oceans where it forms aqueous solutions of carbonates. Thus, the oceans of the world act as powerful buffers that maintain the balance of carbon dioxide in the atmosphere. Nevertheless, a noticeable—though as yet slight—increase in the content of carbon dioxide from 0.03 to 0.032 per cent has already been recorded in the Earth's atmosphere.

The rapid increase in the consumption of fuel minerals will evidently lead in time to a considerable increase in the content of carbon dioxide in the atmosphere. This is of no serious consequence to human beings and animals, but may cause catastrophic changes in the world climate within 200 to 300 years. The carbon dioxide contained in the atmosphere actively absorbs the Earth's infrared radiation. As a consequence, it raises the temperature of the Earth and the lower layers of the atmosphere (due to the so-called hothouse effect) and may in the course of the coming years give rise to a torrid and damp climate on Earth which is wholly unsuitable for people.

The rapid consumption of fuel and the dangerous increase in the content of carbon dioxide in the atmosphere to be expected in the near future make it most urgent to employ basically new sources of energy to meet the power requirements of mankind. And this should be done within at most a 100 years.

* * *

Naturally, what first comes to mind is the fuller use of nuclear energy as such power stations are already in service. The use of this form of energy is, however,

limited due to the Earth's scanty deposits of uranium. It's true, of course, that more deposits of uranium have been found since the discovery of nuclear energy. The point is, however, that uranium-235 is the only fissionable isotope suitable for the production of electric power from nuclear energy and it occurs in nature only to the extent of 0.7 per cent of natural uranium. The remaining 99.3 per cent is uranium-238 that finds no use in the generation of electricity and is lost as waste. With such a state of affairs, it may seem that nuclear energy has no chances of becoming the predominant source of power generation in the future.

Fortunately, it is long known that the capture of a neutron by uranium-238 leads to the formation of plutonium that is an even more active material than uranium-235. This process, however, calls for the use of a neutron source of high efficiency. The idea of developing such a source was first advanced in the Soviet Union in the fifties and later in the United States. This could be a proton accelerator having a capacity of $0.5\text{-}1 \times 10^9$ eV. On reaching the uranium-238 target the fast protons pierce the electronic shell of the atom and penetrate into the uranium-238 nucleus knocking out 30 to 50 neutrons per proton. These neutrons interact with uranium-238 and transmute it into plutonium. This idea was lively discussed both in the Soviet Union and the United States until recently.

But this has led in both countries to a much more simple way of utilizing uranium-238 in the so-called breeders. Prototypes of such breeders have already appeared in the United States, the Soviet Union and France. Efforts are now directed towards the development of optimum types of plutonium breeders. The fission of an atom of plutonium liberates about three

neutrons. One of the neutrons serves to perpetuate the nuclear chain reaction lying at the base of operation of nuclear power stations. The second neutron is absorbed by the uranium-238 shell of the breeder and contributes to the production of plutonium which recharges the breeder after the initial charge of plutonium is exhausted. Finally, the third neutron of every atom is either lost or serves in part to obtain an additional amount of plutonium in operating reactors, thus allowing to "breed" atomic reactors. This process makes it possible to utilize a larger part of the available uranium as fissionable material. In other words, this provides for a nearly 100-fold increase in the effectiveness of the extracted uranium ore, and makes it economically justifiable to extract even poor uranium ores or even to extract uranium from sea water. Though the concentration of uranium in sea water is extremely low (five milligrams per ton), its total amount in the oceans of the world is 1000 times higher than in the Earth's crust.

The number of breeders is at present increasing at a relatively low rate (approximately doubling every ten years). In 50 years, however, a major part of the world energy output will be contributed by nuclear power stations.

In principle, the method of breeders is quite feasible and it is only a question of their further technological improvement. The advantage of the method is the absence of radioactive gases liable to contaminate the surrounding atmosphere, with the exception of small quantities of krypton that have to be eliminated at large-scale generation of electricity by this method. Its disadvantage, however, is that in the course of time practically all the available resources of uranium and thorium will be converted into large amounts of residual radioactive products, which may have harm-

ful consequences. Therefore, it is essential to fully guarantee that the fission fragments will not contaminate soil waters for hundreds of years even when buried deeply underground. So far, experiments have yielded satisfactory results. But taking into consideration that an ever greater number of atomic reactors will be put into service in the near future, it is necessary to thoroughly investigate the burial conditions of the residual radioactive products so as to exclude any possibility, however slight, of their penetration into the surroundings.

Completely new opportunities for the future power generation are offered by the development of controlled thermonuclear reactions. The harnessing of such reactions for useful purposes seemed at first to be quite impossible in view of the enormous amounts of released heat with the corresponding extremely high temperatures occurring within the reaction zone, temperatures attaining a value of several hundred millions of degrees and more. Such temperatures are necessary for the reaction to be sufficiently fast and self-sustaining. Of course, it's quite evident that the shell of the thermonuclear reactor would evaporize immediately at such high temperatures, unless special measures are taken to prevent that. However, physicists advanced the idea of magnetic confinement of the reaction. This solved the problem of reducing the heat transfer to the reactor shell and made such a controlled process in principle realizable. The passing of a strong current pulse through the active material raised its temperature to a level closely approaching that needed to start the thermonuclear reaction. This has also made it possible to check the effect of the magnetic confinement.

After it had been proved that the method of magnetic confinement was quite practicable, scientists be-

lieved that controlled thermonuclear reactions could be brought into being within the next ten years. Prominent scientists of many countries, including the Soviet Union, directed their efforts to solving this problem and found, unfortunately, more and more difficulties sprang up in the course of deeper study of the problem. Now it has become more or less clear what difficulties have to be overcome in order to achieve and maintain a stable thermonuclear reaction.

From the very beginning, the attention of scientists was drawn to two different types of thermonuclear reactions. The first one is the bimolecular reaction of the nuclei of gaseous deuterium

$$D + D = He^3 + n$$

where D is the nucleus of deuterium (a hydrogen isotope) containing one proton and one neutron, and He^3 is a helium isotope with a nucleus made up of two protons and one neutron; this reaction, in essence, amounts to two successive reactions

$$D + D = T + p \qquad (1)$$

where T is the nucleus of tritium (a hydrogen isotope) consisting of one proton and two neutrons; and

$$T + D = He^4 + n \qquad (2)$$

where He^4 is ordinary helium with a nucleus containing two protons and two neutrons; n stands for "neutron", and p—for "proton".

The last stage of the reaction proceeds at a much higher rate than the first two stages. Therefore, the final products of the reaction are practically free of the weakly radioactive tritium.

The second type of thermonuclear reaction proceeds in the following manner:

$$T + D = He^4 + n$$

This reaction is easier to achieve than the first one, but calls for the synthesis of tritium that does not exist in free state on Earth. The initial charge of tritium can be obtained in the usual atomic reactors and then bred—as will be shown later—by the neutrons liberated in the course of the thermonuclear reaction. To this end, the reactor has to be surrounded by a shell made of chemical compounds of lithium. Natural lithium contains 7 per cent of the Li^6 isotope. The neutron slowed down in the lithium shell gives rise to a reaction whereby $n+Li^6=He^4+T$. The resultant tritium is extracted and again used in the basic process. Moreover, a reaction yielding two neutrons for every single neutron can be brought about if a layer containing beryllium is placed between the reactor and the shell. Both neutrons interact with the Li^6 isotope and produce two atoms of tritium. The amount of tritium obtained in this way not only compensates for its consumption in the course of the reaction, but also gives a surplus that may in principle be utilized to develop new thermonuclear reactors.

The thermonuclear reactions of both types give up an enormous amount of heat. In the first case, the energy released per gram of gas is equal to that obtained on combustion of approximately 10 tons of coal, and in the second case, of 14 tons of coal. Both reactions take place at temperatures in the vicinity of 100 million degrees. At these temperatures, the gas becomes a plasma consisting of electrons and positively charged nuclei. Let us consider a reactor wherein the temperature of the plasma is raised instantly to the required level by a series of rapidly applied current

pulses. The trouble is that the plasma burns stably only for a very short period of time τ which is determined by the strength of the magnetic field and the design of the given reactor. For the reaction to develop to a sufficient extent, it is essential that its duration t be shorter than τ. In other words, the reaction proceeds satisfactorily only when $\tau/t>1$. The rate of the reaction is given by equation $W=KN^2$, where N is the number of nuclei per cm^3, and K is the reaction rate constant for the given temperature. K equals 100 million degrees for the T+D reaction and is of about an order higher in the case of the D+D reaction. Hence, the duration of the reaction $t=1/KN$ and the condition under which the reaction proceeds satisfactorily may be expressed as follows: $KN\tau>1$. Constant K of the bimolecular reaction is as usual in proportion to the cross section $\sigma=\pi r^2$ of collision of the particles in question or, in our case, of the nuclei. Radius r gives the maximum internuclear separation distance at which the thermonuclear reaction can be expected to proceed normally.

The cross section of reaction D+D has proved to be 100 times smaller than that of reaction T+D. Accordingly, constant K of the first reaction is 100 times lower than that of the second one. Therefore, the numerical value of product $N\tau$ amounts to 10^{16} for the case of the deuterium reaction, and to 10^{14} for the tritium-deuterium reaction. Consequently, the tritium-deuterium reaction can be achieved much more easily.

Up to date, a figure of $N\tau=10^{12}$ has already been attained experimentally, and there are sufficiently reliable grounds to believe that a figure of 10^{14} needed to start the tritium-deuterium reaction will be obtained in time.

The tritium-deuterium thermonuclear reaction suffers, however, from three disadvantages. The first is

due to the necessity of employing the lithium Li^6 isotope in the same quantities as tritium and deuterium. The world resources of lithium ores (and, also, mineralized waters) explored to date are rather limited, especially on taking into account that there is only 7 per cent of the Li^6 isotope in natural lithium. If future power generation were to rely in the main on the T+D thermonuclear reaction, the explored world resources of Li^6 would run out fully within a comparatively short time. Lithium is a highly dispersed chemical element, and although it is of a sufficiently high total content in the Earth's crust, it can be found only in very low concentrations. For instance, its content in granites is not above 1/1,000 to 1/10,000 fractions of per cent. Naturally, the processing of such ores is not profitable.

The second difficulty with tritium stems from the fact that it is very hard to avoid its losses and gradual contamination of the atmosphere. And tritium is, unfortunately, a radioactive element. Therefore, the employment of this reaction calls for thorough safeguard against radioactive contamination or, in other words, for the removal of tritium from the expelled gases.

The D+D reaction is, of course, accompanied by the appearance of tritium as an intermediate product. In this case, however, it reacts almost instantly and disappears completely in the course of the T+D reaction.

Thirdly and finally, it is a rather difficult technological task to combine the extraction of tritium from the reactor lithium shell and the utilization of released heat for the operation of conventional power station boilers. It should be noted that $^7/_9$ of the energy released by the T+D thermonuclear reaction is carried away by fast neutrons within the shell, whereas only $^2/_9$ of the total energy is liberated in the reactor.

In the long run, all these disadvantages of the tritium thermonuclear reaction—even if it were to be put into practice—do not make it more promising than the breeder method. Therefore, the practical implementation of the T+D reaction may be regarded only as a starting point to solving the problem on the base of the D+D reaction. It has been shown that this reaction is a hundred times more difficult to achieve than the T+D reaction. Yet, there is no reason to doubt that man's ingenuity will help him to achieve that goal, though this may demand strenuous efforts and take some scores of years to attain it.

From this optimistic viewpoint, it is of major importance to develop and build suitable power station reactors for the T+D reaction in order to accomplish the D+D reaction in the future.

A few words should be said about the prospects of the future development of the D+D reaction. Over the last twenty years, all efforts were directed in a single direction, with no basically new ideas to proceed from. Some ideas should undoubtedly appear in due time. Incidentally, attention must be paid to the new and original idea advanced by Soviet Academician Basov and several French scientists. They proposed to raise the temperature of solid compounds of deuterium or of directly frozen deuterium by laser-emitted pulses.

Basov aimed a narrow laser beam at a target of lithium deuteride. The best results were obtained with very short pulses, when the plasma—developed by the heat of the laser beam—hadn't sufficient time to expand. The experiment recorded a slight yield of neutrons, this indicating that a weak thermonuclear reaction had actually taken place. According to this method of developing the thermonuclear reaction, the plasma does not require any magnetic confinement. Though τ is of a very low value in these experiments, the nuclei

are of quite high concentration since the plasma occurs in a solid body.

The beam of the laser is made to strike a very small quantity of the active material. Then the series of laser pulses is interrupted for a short period of time, another small portion of the material is set in place, and so forth. Thus, the installation operates in the same way as an automobile engine where the fuel is supplied to the cylinders in small quantities.

Not so long ago, a group of American physicists advanced another ingenious method of obtaining thermonuclear energy with the use of the energy of laser beams. So far, only theoretical data has been published, and there are as yet no reports as to whether experiments have been carried out. By this method, a spherically converging luminous flux is cast upon a spherical particle of solid deuterium or deuterium and tritium. The flux ionizes and is absorbed by the surface layer of the particles. As a result, the surface layer bursts asunder, imparts a pulse recoil to the remaining part of the particles and compresses them. By setting a definite dependence of the pulse recoil on time (correspondingly programming the waveshape of the laser pulse), the particle can be compressed almost adiabatically to a density 10^4 times higher than the initial density and made to have up to 10^{27} of deuterium atoms per cm^3. The resulting high temperature rise ensures rapid progress of the thermonuclear reaction. According to calculations, 2 megajoules of thermonuclear energy can be obtained from 60 joules of laser energy. As in the case of the method proposed by Academician Basov and French scientists, the thermonuclear combustion occurs in a series of rapidly alternating small thermonuclear explosions caused by the transmutation of a few tenths of micromoles of deuterium into helium at normal pressure.

When a solution to the problem of maintaining a thermonuclear reaction with the sole use of deuterium is found, it should be placed at the base of future world power generation as it possesses several undeniable advantages over all other means of meeting man's energy requirements. First and foremost, the resources of deuterium are unlimited and do not call for any labour-consuming mining work. The raw material in this case is simply water available in unbounded quantities in oceans and seas, which contains deuterium to the extent of $^1/_{350}$ of the weight of hydrogen and $^1/_{6300}$ of the weight of water. Taking into consideration that the heat released by one gram of deuterium in the course of the thermonuclear reaction is equal to that obtained by burning 10 tons of coal, it becomes evident that the resources of deuterium in the world ocean are practically unlimited. Deuterium is extracted from ordinary water by well-developed methods. The energy obtained at present from the combustion of all the fuel minerals extracted annually in the world can be derived from the deuterium contained in a cube of water having a side of 160 metres. The second advantage of this reaction is the practically complete absence of any radioactive contamination. The He^3 and He^4 end products of the reaction are non-injurious to health.

Is there a limit to the utilization of thermonuclear energy? However strange, such a limit exists due to the temperature rise of the Earth's surface and atmosphere resulting from the liberation of heat within thermonuclear reactors of the future. Calculations show that the average temperature will rise on land and sea by 7 degrees C when the heat released by thermonuclear reactors becomes equal to 10 per cent of the solar energy absorbed by the surface and oceans of the Earth and the lower strata of its atmosphere.

Such a rise in the average temperature on land and sea will inevitably cause a sharp change in the Earth's climate and may even lead to a new Flood as a result of the thawing of Antarctic and Greenland ice. Therefore, it is hardly reasonable to raise the output of thermonuclear energy above 5 per cent of the solar energy, a figure at which the temperature of the Earth's surface will rise by 3.5 degrees Centigrade. It would, however, be of interest to obtain accurate calculations of the danger presented by heating the Earth's surface.

The Institute of Oceanology of the USSR Academy of Sciences has in this connection taken upon itself the most difficult and unprecedented task of making exact calculations to ascertain what will happen to the icebergs and ice of the Antarctic region and Greenland with a few degrees increase in the Earth's average temperature. Will this cause only a certain stationary change in the climate and reduce the number of icebergs in those regions or will a certain critical rise in temperature bring about a progressive thawing of the glaciers?

The results of those calculations are of great interest not only as an answer to that question, but also for further development of the theory of ice ages and the processes of warming the Earth's climate. There are also many other more specific problems that have to be solved such, for instance, as that of offering a satisfactory explanation of the appearance of comparatively warm oases discovered in the Antarctic.

It's rather difficult at the present stage to say what exact temperature rise of the Earth may cause irreversible changes in its glacial cover and climate. Yet, I'd say that the accepted increase of 3.5 degrees due to the energy output of all thermonuclear and atomic power stations seems rather overestimated.

Let us find the upper limit values of nuclear energy output. As mentioned earlier, an increase in the average temperature by 3.5 degrees occurs when the heat liberated by all nuclear installations does not exceed 5 per cent of the total solar radiation absorbed by the Earth's surface and the adjoining lower strata of its atmosphere.

The solar energy reaching the Earth amounts to 4×10^{13} kcal/s. Thirty per cent of the solar radiation is reflected by the Earth's surface and lost in outer space, a significant part is absorbed by the higher strata of the atmosphere, etc. The surface of our planet and the adjoining part of the atmosphere receive less than 50 per cent of the total energy sent by the Sun, i.e., 2×10^{13} kcal/s; 5 per cent of that energy constitutes 10^{12} kcal/s, or an annual figure of $10^{12} \times 3 \times 10^{7} = 3 \times 10^{19}$ kcal/year.

Proceeding from our assumption, this is the maximum permissible thermal energy that can be derived from all thermonuclear and atomic power stations of the world. Let us compare that figure with the amount of energy obtained at present from fuel minerals (oil, gas and coal). As mentioned above, the annual output of fuel minerals stands now at a level of 6×10^{9} tons of reference fuel having a heating value of 7×10^{6} kcal/ton, this giving an annual figure of 4.2×10^{16} kcal/year. Thus, the harnessing of thermonuclear power would yield $3 \times 10^{19}/4.2 \times 10^{16} = 700$, that is 700 times more energy than the energy obtained now from mineral resources. This figure may be slightly exaggerated and in reality the energy derived from thermonuclear reactions might be only 500 or even 300 times greater than that obtained by burning fuel minerals. Nevertheless, such an amount of energy would probably be sufficient to meet the future power requirements of mankind, provided the popula-

tion of the Earth and, particularly, of South-West Asia does not start to grow by more than the present-day figure of 1.7 per cent per year in the next few centuries.

* * *

Wide prospects are offered to mankind by more efficient utilization of solar energy. The Sun delivers 4×10^{13} kilogram calories to the Earth per second. Unfortunately, only about 50 per cent of this energy reaches the Earth's surface since the other half is dispersed and absorbed even in an absolutely clear atmosphere. Clouds, dust and so forth reduce the figure to 40 per cent. Yet there still remains an enormous amount of solar energy that is scores of times greater than the energy which can be obtained from the maximum permissible utilization of controlled thermonuclear reactions.

The origin of life on Earth is closely linked with the appearance of first microscopic and then quite large plants which in the process of evolution developed a means of photosynthesis by which the energy of the Sun transforms carbon dioxide and water into organic matter and, at the same time, liberates bound oxygen. The latter reaction is responsible for the appearance and maintenance of oxygen and, also, for the stable content of carbon dioxide in the Earth's atmosphere. The combined effect of all those factors led eventually to the appearance of the animal world.

The Earth's wealth of fuel minerals originates from the decay of plants and—to a lesser extent—of animals. In other words, fuel minerals have accumulated the solar energy received by the Earth in the remote past. Thus, modern industry has actually been created thanks to the work done in the past by solar energy. Plant and animal food that maintains the life and

labour of three to four billion of the world's population has been obtained with the aid of solar energy as a result of the process of photosynthesis going on in cultivated plants consumed directly by man or serving as fodder for farm livestock yielding meat, milk, eggs, etc. Man—viewed as a muscular machine—works with a quite high efficiency factor as a result of the transformation of the energy stored in food by a process of slow "flameless" oxidation within the human body, in contrast to the rapid combustion of fuel in flames within boilers and engines. The efficiency of the human mechanism is, by the way, as high as 30 per cent, i.e., of the same order as that of internal combustion engines. The efficiency of conversion of chemical energy directly into the work of muscles attains 70 per cent, i.e., is nearly 1.5 times higher than the efficiency of the best electric power stations. This is really not surprising at all since the energy processes taking place in the human body differ greatly from those in industrial installations and may in principle provide for the conversion of energy with a 100 per cent efficiency. A striking illustration is the way in which glow-worms convert chemical energy into light.

Similar slow processes of combustion occur in such chemical systems as fuel cells, wherein the efficiency of conversion of chemical energy into electrical energy closely approaches 100 per cent. Unfortunately, a high efficiency has been attained as yet only in hydrogen-oxygen cells, though in future it will probably become possible to replace expensive hydrogen by petroleum hydrocarbons.

A major part of mankind is at present underfed, and there still are places on Earth where starvation is of common occurrence. Yet, the entire population of the Earth and, evidently, an even greater number of people could be provided fully with high-quality food by

a sole improvement in the methods of cultivation, fertilization and irrigation of existing arable lands (let alone expansion of sown areas). At present, average crop yields are still at a rather low level.

Anyhow, at a sufficiently high level of agricultural management and sufficient irrigation and fertilization, harvests of about 15 tons of dry products are obtained per hectare of cultivated land. Certain crops, such as maize, sugar cane and other tropical plants, yield up to 40-50 tons of dry product per hectare. In the case of crops meant for direct supply of food to the population (say, grain crops), 40 per cent of the 15 tons of dry organic product mentioned above, i.e., 6 tons of the product, is put to direct use. In the case of crops grown as fodder, practically all the yield of 15 tons is used to feed farm livestock, but only a minor part, namely, 10 per cent or 1.5 tons, is obtained from the livestock as meat, milk, butter, bacon and eggs (in terms of dry weight).

The optimum daily ration of man is about 1 kg of dry food, vegetable food accounting for about 750 grams of that amount, and animal food, for about 250 grams. Only 130 million hectares are needed to feed the world population of 3 billion, and 180 million hectares more for fodder. This amounts to a total of about 300 million hectares, or 2.2 per cent of the Earth's dry land (without the Antarctic region). And this is 4 to 4.5 times less than the present-day area of cultivated agricultural land. The conclusion to be drawn—knowing man's present average ration to be below established standards—is that present-day average crop yields are greatly below what they could be. It follows that a much larger population than exists at present could be amply supplied with food by raising the cropping capacity of existing cultivated agricultural land to a higher but quite attainable level.

If mankind had practically unlimited power resources for irrigation and reclamation of land, for heating hotbeds and greenhouses (and supplying them additionally with carbon dioxide) and had developed inexpensive and durable plastic films to cover the hotbeds and soil, as well as suitable sealing materials to prevent the loss of moisture in sandy soil, all this would offer wide opportunities of raising the yield of cultivated land and reclaiming unproductive land. The main problem, however, is not that of expanding cultivated areas, but of improving the cropping capacity of existing lands by better agricultural management, irrigation and plant breeding as these measures will bring about a 5-fold increase in the output of food products from existing cultivated areas. Should the Earth's population continue to grow at the present rate, it will increase 5-fold in the course of a hundred years. Thus, the limiting factor will be not food, but the energy needed for further industrial development and, in particular, for the manufacture and operation of agricultural machines, the production of fertilizers and improvement of the people's living conditions.

Now, let us compare the total annual output of fuel minerals (in tons) with the world annual output of food and fodder (also in tons of dry weight).

The world yield of crops amounts at present to about 7.5×10^9 tons a year, i.e., is slightly above the annual output of fuel that stands at a level of 6×10^9 tons. The caloricity of food and fodder in dry form is about 4×10^6 kcal/ton as compared with 7×10^6 kcal/ton of reference fuel. Hence, it follows that the caloricity of the annual output of food and fodder amounts to 70 per cent of the caloricity of annually extracted fuel. Besides, account has also to be taken of industrial crop (cotton, flax, etc.), forest utilisation and so forth.

The total annual amount of world products of photosynthesis on land and sea is assessed (very approximately, of course) at 80 billion tons, i.e., is about 14 times greater than the annual output of fuel (in terms of caloricity, it is 7 to 8 times greater). This is, naturally, a very rough estimate as it is very difficult to establish the exact figure of photosynthetic production on land and sea. It now has become clear, however, that the photosynthetic production of seas and oceans is not greater than on land, though the surface of the former is 4 times that of land. Let us have a look at the productivity of forests, where it is possible to make a more exact estimate.

The total area of land covered by forests is approximately equal to 4×10^9 hectares or 4×10^7 square kilometres, and accounts for about a third of the Earth's dry land. The trees have a rather high efficiency of photosynthesis. Thus, the products of photosynthesis of northern forests amount to 8 tons per hectare, and tropical forests exhibit a much higher figure. The calculations are only made for commercial timber and do not take account of the knots, roots and substandard trees. It is assumed that the world average annual output stands at 10 tons per hectare. It follows that the annual output of all forests is 4×10^{10} tons, i.e., equals 40 billion tons of timber. This is 7 times higher than the annual output of fuel (in tons) and 4 times higher in caloricity.

Needless to say, it is unreasonable and wasteful to burn timber that is a valuable building material and source material for the production of paper pulp and many other organic substances. The combustion of waste timber alone is, however, sufficient to meet all the power requirements of forestries. Unfortunately, the greater part of the gain in timber is not put to use, it rots because of improper management and the dif-

ficulty of shipment from the northern and tropical regions. The immediate task is to take proper care of forests and their felling.

The figures cited above may at first glance seem to be rather overstated. They are, nevertheless, insignificant in comparison with the energy of the solar radiation reaching the Earth. The efficiency of conversion of solar energy into chemical energy of food and fodder is seen to be 1.5 per cent with the high crop yields mentioned above (15 tons of dry weight per hectare) and five times lower with the contemporary average yields. (The efficiency of photosynthesis is determined by the ratio of the crop yield caloricity—in dry weight—to the solar radiation per hectare expressed in the same units, say, in kcal/ha. Biologists usually determine the efficiency of photosynthesis for the visible part of the solar spectrum only, that accounts for half the energy of the solar spectrum and is responsible for the process of photosynthesis. Thus, the adopted efficiency of 1.5 per cent corresponds to a "biological" efficiency of 3 per cent.)

Such a low efficiency is due, first and foremost, to the fact that when the plants are still small at the early stages of vegetation, their leaves cover but a small area of the ploughed fields and the greater part of the solar energy is absorbed by the soil rather than the plants themselves. At full development of the plants, some of the leaves are in the shadow of others, and the solar energy is received only by the upper ones. All this hinders the course of the physiological functions of the plants and lowers the efficiency of photosynthesis since the latter is about 10 per cent at little sunlight, but falls with increasing intensity of sunlight. At high intensities of radiation, the output of matter in general ceases to depend on the intensity of light, and the rate of development of the photo-

chemical process is confined to fermentive activities, diffusion of source materials within the plant and so forth.

In view of those peculiar features of the efficiency of photosynthesis, it would be of considerable advantage to provide for even distribution of the solar energy among all the leaves of the plants, so as to increase their active surface, maintain the process of photosynthesis at a low intensity of light and, consequently, keep it at a high level of efficiency. Such conditions are, evidently, created on maize fields for two to three weeks prior to harvesting and for second-year plants on sugar cane plantations. A peculiarity of those crops and of many other tropical plants is that their long leaves are at a small angle to their stalk. This makes it possible—and especially in southern regions—for the sunrays to penetrate deeply into the mass of the crop. In consequence, the sunlight reflected from and passing through the leaves, though of low intensity is distributed evenly within the mass of the crop. This makes the efficiency of photosynthesis much higher than in the case when the sunrays directly strike the dense upper layer of the foliage. At the mentioned stage of development and under proper agrotechnical conditions, the efficiency of photosynthesis within those plants attains 7 per cent of the received solar energy.

This high efficiency of photosynthesis is determined by a wide variety of factors (shape and arrangement of the plant leaves, crop management, etc.) and not by the mechanism of the process of photosynthesis alone.

The initial efficiency and changes in photosynthesis are not exactly the same for different plants; they in general fall into two groups. The first group includes all plants of moderate climate regions, and the second group covers all tropical plants. The efficiency of

photosynthesis of plants of the first group has—at low intensities of light—an average value of 8 per cent, whereas that of plants of the second group is at an average of 12 per cent, these figures corresponding to a "biological" efficiency of 16 and 24 per cent, respectively. This circumstance is, by the way, one of the reasons for the high crop yield of maize, sugar cane and other similar plants.

* * *

Thus, solar energy is capable—in combination with agrotechnical measures and plant breeding—of providing mankind with sufficient food for the next two centuries even with a considerable growth of the Earth's population.

In view of the fact that the world resources of fuel minerals accumulated in the course of millions of years by the work of solar energy are gradually running out, let us see whether there is a possibility of deriving enough electrical energy for industrial and domestic needs from that same solar energy. Or maybe solar energy could be utilized to obtain organic products by chemical processes similar to those occurring in plants?

Wide use is made nowadays in outer space flights—and, especially, in the exploration of the lunar and martian surfaces—of semiconductor solar cell batteries having an efficiency of over 10 per cent. There can be no doubt at all that in the near future scientists will find means of raising the efficiency of conversion of solar energy into electrical energy to a level of, say, 20 per cent. In contrast to the process of photosynthesis in plants, the efficiency of solar cell batteries does not drop with rising intensity of solar energy.

In principle, further reduction of the cost of semiconductor materials may make it quite feasible in future to derive energy by covering large areas of land with such cells. The daily, monthly and annual fluctuations in the intensity of solar radiation and, consequently, of the current generated by solar cells could well be smoothed out by accumulating the electrical energy in products of electrolysis. The type of electrolysis could be selected so that its products would provide for about a 100 per cent conversion of the chemical energy into electrical energy in fuel cells or conventional cells. Such cells would serve as electric power sources of constant capacity.

The photocells of the battery must of necessity be arranged over a wide area and reliably enclosed in sturdy plastic shells. The maintenance of such "energy fields" would probably be no more time-consuming than that of ordinary agricultural fields.

Nevertheless, that can hardly be said to be an optimum solution of the problem of harnessing solar energy, as it calls for the employment of a vast amount of expensive semiconductor material. It is, of course, possible to obtain and use certain less expensive organic semiconductor materials. These materials are, however, still in the stage of development and so far the efficiency of such batteries is exceedingly low (about 2 per cent). This does not, of course, exclude the possibility of future improvement of those materials and attainment of higher battery efficiencies.

Yet, I'd say that the problem has to be tackled by quite different means.

Let's begin from afar. About 150 years ago, the German chemist Weller started off a revolution in chemistry by accomplishing the synthesis of urea. Before that, chemists firmly believed that organic matter could appear only in live organisms as the re-

sult of the effect of mustic forces of vitality. Naturally, such a viewpoint was an obstacle to the development of organic chemistry. Weller shattered the superstition and opened the way for a rapid development of organic synthesis. Organic chemistry became one of the most developed sciences that led to the creation of an enormous industry at the close of the last and the beginning of the present century.

At the same time, organic chemistry began to contribute more and more to the development of biological science. The revolution witnessed in biology in our days is largely due to the successes achieved in chemical studies and, first and foremost, the study of the chemistry of natural compounds. All this led to the appearance of molecular biology and bioorganic chemistry.

The development of those sciences revealed that chemical reactions proceed in live organisms in quite a different way than in laboratories and chemical factories. Thus, Weller was right only to a certain extent. We are now capable of synthesizing any organic product, including protein and have even started to synthesize nucleic acids that lie at the base of life. However, the mechanism and very principles of synthesis of these products in organisms differ from those used in laboratories. The complex processes of synthesis last only a few minutes within plants and especially animals, whereas in laboratories they often take up several months of work.

We are on the eve of a revolution in chemistry induced this time by biology. While the chemical industry resorts to high temperatures and pressures to achieve the necessary reactions, they proceed in organisms at usual temperatures and pressures.

* * *

The initial source of energy consumed by plants is solar radiation. In the case of animals, the energy is derived from the oxidation of food products and goes to maintain the reactions which take place in the organism and the work of muscles. This energy is stored as chemical energy in the molecules of adenosine triphosphoric acid (ATP). When energy is consumed by an organism, the adenosine triphosphoric acid is transformed into adenosine diphosphoric acid (ADP) that, in turn, is recharged by solar energy and changes again into a molecule of ATP.

Plants consume—first and foremost—carbon dioxide and water, whereas animals consume plant and animal food. In both cases, use is made of highly specific catalysts known as ferments that are, essentially, enormous protein molecules having small active groups. These active centres quite often contain metal ions of variable valency.

It's impossible to go here into the details of the mechanism of the chemical reactions occurring in general within the organism, or in its individual cells. The cell resembles a miniature chemical and power-producing factory with special workshops responsible for the charging of ADP, distribution of the products of reaction among separate zones, transportation of amino acids and assembly of protein molecules. The process of assembly is conducted by a special "control machine". The accuracy of production and assembly of the components of protein molecules is higher than that encountered in aircraft assembly. In this respect, nature has created a miniature factory of perfection unattainable as yet in industrial enterprises of our days. Therefore, it may seem at first sight that such a complicated mechanism can hardly be expected to

be reproduced and put to use for practical purposes at the present stage of technological development.

This is, however, not quite so. The point is that all the processes taking place in an organism are closely interlinked. Every element of the organism and of individual cell has to ensure a proper interrelationship of all the functions of the entire cell and the entire organism. To pick out and reproduce only one of the functions of the organism, i.e., to obtain only one of the products of synthesis of the organism by some artificial means is, of course, a more simple task. We shall in due time be able to reproduce any of the natural chemical processes by simple means without necessarily copying the laws of nature. To this end, it is sufficient to make practical use of only some of the principles prompted by nature. The achievement of this goal will bring about a revolution in chemical technology.

This can be illustrated by the way in which fixation of atmospheric nitrogen was achieved artificially at normal temperatures and pressures. What I have in mind specifically is the method of production of ammonia and its derivatives from atmospheric nitrogen and water, a method developed over the last few years by Soviet scientists Volpin and Shilov.

Before, this kind of synthesis was known to occur only in the tubercles of bean plants and in certain freely living bacteria. It is a well-known process and it is widely used in agricultural chemistry to increase the amount of bound nitrogen in weak soils. Biologists and biochemists revealed that the process of fixation of nitrogen is set up and maintained by specific bacteria living in the soil or in the tubercles of various bean plants. The reaction is brought about by special ferments of those microorganisms. These ferments (as well as other ferments) are enormous protein molecules

with small active groups containing minute quantities of molybdenum or vanadium ions. It was also noted that the fixation of nitrogen in plants takes place in the presence of magnesium chloride. Biochemists made several attempts to discover the mechanism of the action of those ferments.

As mentioned, Soviet scientists implemented the reaction by artificial means and conducted it at a rate close to that encountered in nature. Complex compounds of variable-valency ions were employed instead of ferments.

In 1964, Volpin was the first to reduce nitrogen to a nitride in nonaqueous solutions of systems similar to the Natt-Signer catalysts. In 1966, Shilov showed that the ions of metals of variable valency form durable compounds with atmospheric nitrogen at low temperatures. The nitrogen—a normally inert gas—proved to be very active under those conditions and capable of displacing water and ammonia from the system of those metals.

An interesting fact is that the systems of metals of variable valency when combined with nitrogen proved to be very stable. With certain metals, they decomposed only at temperatures of approximately 200° C.

By conventional methods, Shilov obtained a loose, floccular and amorphous deposit of vanadium hydroxide $V(OH)_2$ which contains magnesium ions and molecules of water as ligands (systems of molecules and ions linked with a central ion) from aqueous solutions of vanadium salts at an excess of magnesium salts and with the addition of alkali. At saturation of the solution with atmospheric nitrogen, the deposit became an effective catalyst producing hydrazine H_2NNH_2, and —on varying certain factors—directly producing ammonia. The reaction proceeded at such a high rate that it had to be conducted at a temperature closely

approaching the freezing point of the solution. In any case, the rate of the reaction was not below that of the fixation of nitrogen in Azotobacters.

It should be pointed out that the reaction of obtaining hydrazine from molecular nitrogen and water is extremely endothermic and needs the expenditure of over 120 kcal per gram-mole of hydrazine. From what source is such a considerable deficit in energy compensated? It appears that the source of energy is the transition of bivalent vanadium into trivalent vanadium, i.e., from $V(OH)_2$ into $V(OH)_3$.

Indeed, in order to obtain one molecule of hydrazine, four atoms of vanadium have to become trivalent. Thus, the energy released at every stage of the reaction is several times greater than needed to obtain hydrazine from nitrogen and water. It was surprising that the energy of activation of the reaction proved to be in general rather low (of the order of 10 kcal per gram-mole). Actually, this is why the reaction proceeds at a high rate even at temperatures approaching zero.

By carrying out special experiments with the aid of an infrared spectrometer, Shilov established the structure of the initial systems of transient metals and nitrogen in nonaqueous solutions. In the case of vanadium, the structure is evidently as follows:

$$(OH)_2V \ldots N\underline{:::}N \ldots V(OH)_2$$

In other words, the first and second bonds of the nitrogen weaken but do not break off in the presence of two ions of vanadium. These bonds weaken to a certain extent, but instead of that a sufficiently strong interaction is set up between every atom of vanadium and atom of nitrogen. Then occurs a stage in which the following reactions evidently take place simul-

taneously:

$$(OH)_2V \ldots N \underline{\vdots\vdots\vdots} N \ldots V(OH)_2 + (OH)_2V \ldots$$
$$\ldots V(OH)_2 + 4H_2O \rightarrow H_2N - NH_2 + 4V(OH)_3$$

The experiment showed that four molecules $V(OH)_2$ converted into $V(OH)_3$ are spent in forming a molecule of hydrazine.

The mechanism of the reaction leading to the production of hydrazine is as yet not quite clear. Most likely, the ions of magnesium and vanadium form a complex catalytic system containing molecules of water as ligands. It has already been mentioned that molecular nitrogen is capable of displacing water from the system of metals of variable valency. Apparently, this is also a case where one or two molecules of water are replaced by a molecule of nitrogen that penetrates in this way into the vanadium system. As is the usual case in such systems, all the molecules of the system are closely packed. Therefore, a slight thermal impetus of a few calories per mole is sufficient to start the chain of reactions that lead to the production of hydrazine.

This process will apparently imitate the process taking place in live microorganisms (Azotobacters). Yet, it will be many times simpler. It is already quite evident at the present stage of research work that this incredibly complicated reaction can be reproduced in an easy and simple manner that does not need the employment of complex ferments since they are replaced by an active group of ferments comprising vanadium ions. This confirms that the complexity of biological processes is due to the multifunctional tasks of ferments in live organisms. On reproducing the reaction by artificial means, the catalyst performs a single function—that of maintaining the reaction. To

this end, it is enough to deal only with the active centres of the ferment.

In general, this is only natural, otherwise life simply couldn't have appeared on Earth. Live organisms could only appear in the past from inanimate matter. This means that the reactions needed to create the conditions of life, i.e., the reactions of production of free oxygen in an atmosphere of various organic substances and ammonia should have been going on in a primitive but active manner in preorganic nature. This primitive organic matter and ammonia could have given rise to the wide range of nitrogen containing compounds, including protein, now encountered in nature. Thus, the reactions of primary photosynthesis taking place without the participation of any organism and leading to the appearance of oxygen and formation of organic compounds made up of carbon dioxide and water, as well as the reactions producing ammonia from nitrogen and water, should have been going on long before the appearance of life on Earth. At the time of origin of life, the temperature of the land and seas could hardly have been excessively high. Therefore, the reactions under consideration could be maintained only catalytically. In the course of further biological development, those catalysts became ferment systems. They retained, however, the previous catalysts in the form of active groups of ferments. Those initial catalysts of the preorganic period were most likely made up in the main of ions of metals of variable valency. All this largely confirms the idea voiced above, and is now being checked on various other kinds of surprising reactions occurring in organisms.

Let's see if there are any prospects of industrial application of the reaction of fixation of nitrogen.

Hydrazine alone is a most valuable fuel. Moreover, it allows the entire range of nitrogen-containing organic compounds to be obtained. It should be noted in passing that hydrazine is easily converted into ammonia. This method of obtaining ammonia cannot, however, compete with the present-day well-developed conventional method of production of ammonia salts from nitrogen and hydrogen. The reaction is conducted at high temperatures and pressures in the presence of heterogeneous catalysts. On the other hand, it should be borne in mind that the process advanced and implemented in 1914 by Haber and Bosch appeared because there were no catalysts capable of maintaining the reaction of fixation of atmospheric nitrogen at sufficiently low temperatures. The higher the temperature, the lower the thermodynamic output of ammonia. At low temperatures, the thermodynamic output becomes practically equal to 100 per cent. In order to raise the output at high temperatures (where the catalyst becomes effective), high pressures were necessary. Now that catalysts capable of operating at room temperature have been discovered, the question naturally arises whether they can be used to develop a new profitable method of production of ammonia. Up to now, this is impracticable since the vanadium hydroxide involved in the process is, in essence, not a catalyst. Indeed, the vanadium ions cease to take part in the reaction on transition from bivalent to trivalent state, as they give up their surplus chemical energy to produce hydrazine. It is, therefore, necessary to extract the hydrazine from the solution and then to transform the trivalent vanadium ions back into bivalent ions by passing an electric current through the solution. This makes the process more complicated and requires the consumption of a considerable amount of electrical energy. For a satisfactory solution of the problem, it

is necessary to recharge the ions in the course of the process of production of hydrazine without spending any additional electrical energy. The process must be made similar to that going on in plants and animal organisms, i.e., either by resorting to the use of solar energy or to the oxidation of some inexpensive organic substances by atmospheric oxygen. Research work in this direction is still in an initial stage. Should it yield satisfactory results, the new process may prove to be the more advantageous. Moreover, if it is achieved with the aid of solar energy, it will offer a solution to the problem of artificial photosynthesis.

Indeed, the light-absorbing stage of the process of photosynthesis gives rise in the final analysis to the reaction of $H_2O + CO_2 \rightarrow O_2 + CH_2O$. This is a typical redox reaction of the same kind as the reaction of fixation of nitrogen and requires approximately the same amount of energy for its sustenance. The reaction could be conducted with similar compounds.

Let us assume that the implementation of this process provides a means of achieving artificial photosynthesis with a high efficiency. Let us also assume that the efficiency of utilization of solar energy has been raised up to a level of 20 per cent, i.e., has been made approximately twice higher than the maximum "biological" efficiency of photosynthesis in plants. Those are, of course, purely theoretical assumptions that as yet have no experimental grounds. Large plastic shells containing an aqueous solution of the initial substances will—according to this method—be arranged over wide areas of energy fields. The reaction initiated within the shells by the energy of solar radiation yields products rich in chemical energy. The solutions circulate slowly and are brought up to substations where the final products rich in energy are extracted and fresh initial material is added. As a result, the

energy "harvest" is continuously reaped from the energy fields.

The actual embodiment of the method may, of course, differ greatly from the picture drawn above. In any case, the energy fields should be located in desert and semidesert regions unsuitable for agricultural cultivation and having a high intensity of solar radiation. The total area of the energy fields we suppose could most likely amount to 10^9 hectares, i.e., be approximately twice less than the area of land taken up at present by cultivated fields and meadows. Take, for instance, the map of Europe, Africa, the Arabian peninsula and a small eastern part of Asia, an area inhabited by a fourth of the Earth's population. The area of the energy fields of that part of the world would cover 2.5×10^8 hectares. It should be noted that the deserts and semideserts of that region cover a much wider area.

North and South America—they account for about a quarter of the world population—also have a large number of deserts and semideserts. The situation is somewhat more difficult in the main part of Asia and the archipelagoes between Asia and Australia since this region accounts for half the world population and yet has only the Gobi desert and some arid areas in the northern and central parts of Australia. It was shown above that the total area of the energy fields equals 10^9 hectares, and their annual energy yield amounts to 3.4×10^9 kcal per hectare. The world annual energy yield constitutes 3.4×10^9 kcal/ha$\times 10^9$ $= 3.4 \times 10^{18}$ kcal available in the form of a product rich in chemical energy. We know that the combustion of the world annual output of fuel minerals gives 5.6×10^{16} kcal. It follows that the utilization of solar radiation would bring about a 60-fold increase in the power resources of mankind.

The harnessing of solar energy as well as of thermonuclear energy requires above all the fulfilment of an extensive volume of research work in those particular branches of science. Many scientists in the USSR and other countries are engaged in research work aimed at putting the controlled D+D thermonuclear reaction into practice. At the same time, the fundamentals of utilization of solar energy have hardly been developed.

The great area of the solar energy fields needed to meet mankind's power requirements seems at first sight rather frightening. It should be recalled, however, that the use of solar energy for food synthesis or, in other words, in agriculture also requires an enormous area of land, large investments and manpower that increase with higher crops.

Utilization of solar energy will not cause any excessive temperature rise of the Earth's surface and, consequently, any noticeable changes in the climate of our planet. It does not present any threat to the environment and is a source of practically infinite energy.

Thus, we have examined the possibilities of utilization of solar energy by the process of artificial photosynthesis carried out in special chemical systems. This does not imply, however, rejection of the purely thermal method of harnessing the Sun. Thirty to fourty years ago, many scientists and engineers the world over took a great interest in designing and even implementing all kinds of solar machines that in general worked fairly well.

It became quite clear at that time, however, that there were hardly any prospects of large-scale use of such installations. Nevertheless, the very existence of the "hotbed effect" set the task of developing a material that would protect the "hotbed" from heat los-

ses into the soil and thermal radiation losses into the surrounding atmosphere so that a temperature of a few hundred degrees could be created at least in the equatorial regions of the Earth.

It's interesting to note that Joliot-Curie, one of those who laid the foundations of development of atomic energy, advanced the problem of utilization of solar energy into the foreground during the last years of his life.

The time has come for international cooperation of scientists in developing the fundamentals of utilization of solar energy by artificial photosynthesis. Extensive research work in this field is of major importance since this may offer most promising opportunities both of meeting the Earth's power requirements and of synthesizing food products and fodder.

The Sun is a source of constant and enormous energy. For the Earth it is the most powerful source of energy. Moreover, the utilization of solar energy makes it possible to control the Earth's climate by cooling hot regions and heating cold ones. All these opportunities are, of course, closely linked with the prospects that will be opened by scientific research work at the close of this century and the beginning of the next century.

The research work should be conducted in all directions that can lead to the development of immense sources of energy (nuclear breeders, thermonuclear reactions, solar energy and maybe terrestrial thermal energy).

* * *

Let us suppose that the controlled D+D thermonuclear reaction will be successfully accomplished. Its maximum output will be 700 times greater than that obtained at present annually from the combustion of

fuel minerals. The thermonuclear reaction will eventually yield an energy ten times greater than the solar energy liable to be derived from the enormous energy fields described above. In this case, is it really necessary to have such energy fields?

It should be borne in mind, however, that the D+D thermonuclear reaction may only be accomplished within a hundred years, and the building of a sufficient number of reactors of this type may take up fifty years more. By that time, the world resources of fuel minerals may already be nearly exhausted and future generations would be deprived of a convenient source of raw material needed for organic synthesis and for the solution of problems that could be tackled by the employment of solar energy fields.

To this end, it is necessary to solve a most difficult scientific problem, namely, that of finding a way of implementing the reaction of photosynthesis, i.e., of obtaining organic products from CO_2 and water with the aid of solar energy. Carbonates offer a practically unlimited source of CO_2. And if the problem is solved, mankind would be able to get an annual output of organic products 60 times greater than the present-day output of fuel minerals. This is the main goal of harnessing solar energy.

This would for ever relieve mankind from the threat of exhaustion of the world resources of fuel minerals needed for organic synthesis. Besides, the organic products reaped from the energy fields could be processed by some of the presently developed microbiological methods or some suitable chemical process, so as to obtain the necessary amount of fodder for farm livestock. At present, the prospects of employing such methods for the production of food are obstructed by the general lack of sufficient oil field resources. In future, however, they may become the main means of food

production. It should be pointed out that with the adopted 20-per cent efficiency of conversion of solar energy into the chemical yield of energy fields, the highest crop yield of present-day cultivated fields (15 tons of dry product per hectare) will be surpassed ten-fold.

With a sufficiently high efficiency of conversion of organic products by the microbiological and chemical industry, the yield of fodder per hectare will be 40 times higher than the present-day figure.

* * *

Abundance of electrical energy will make it possible to obtain any amount of metals. The point is that lean ores require greater amounts of electrical energy for their enrichment and extraction of the metal. Rich deposits will soon be exhausted in the same way as the resources of fuel minerals. Therefore, in time it will become necessary to extract the more low-grade ores and, consequently, use more and more electrical energy for its treatment. On learning how to process lean and usually polymetallic ores, we shall obtain a wide range of metals that are available in large though dispersed quantities in the Earth's crust and the magma beneath the crust and sea beds.

Up-to-date investigations have indicated that we are on the eve of developing profitable methods of extracting gold and especially uranium from sea water though they are contained there in very low concentrations. This has been made possible by the development and use of methods of sorption and, in particular, by the employment of ion-exchange resins and various types of extractive reagents.

Hydrometallurgy based on the dissolving of valuable components of ores in active chemical media and sub-

sequent extraction of the needed elements by sorption and extraction is already rapidly developing into a practical industry and closely competes with pyrometallurgy ("hot" metallurgy).

It's quite possible that with the production of large amounts of inexpensive electrical energy in the near future, this "cold" metallurgy will overtake the "hot" metallurgical industry and in many cases the competition may eventually cause their close cooperation.

Extensive use is made in our days of electrolysis, electrothermal processing and plasma chemistry. Serious changes are to be expected in the field of metal working where electrochemical, electric-discharge machining and laser methods of treatment have become basic methods of metal working. Generally speaking, the enormous future resources of electrical energy will lay the foundation for radical changes in the technological processes employed in the chemical and metallurgical industries, as well as the machine-building and construction material industries.

High-grade refinement of heat- and corrosion-resistant materials, and also semiconductor materials is an extremely expensive process. Unlimited generation of inexpensive electrical energy will make those processes much more accessible.

Cast stone will be widely used in civilian construction and highway engineering. The soil of any constructional site can be transformed into cast material. Large amounts of electrical energy will be required for the electrification of farm work, electric power supplies for tractors and agricultural machines, electrification of hotbeds, greenhouses and other agricultural needs.

We have already discussed the wide opportunities offered by the implementation of methods of sorption and extraction. These and other similar methods will

be used in time for the purification of drainage water making it possible to develop closed water supply systems and reduce by hundreds of times the consumption of water from rivers and lakes thus fully excluding environmental contamination. This is the only practical means of putting an end to the poisoning of water by industrial enterprises that eject large quantities of harmful products into water and also the surrounding atmosphere. An abundance of electrical energy will put things into order. A large network of highly-efficient electric filters and cleaners will be put into service and new types of filtering materials will be employed to remove all traces of injurious aerosols. As regards the more difficult task of getting rid of such harmful chemical gases as sulfur dioxide, nitrogen oxides and waste products of organic synthesis, this calls for the development of new methods that will, in turn, need large amounts of electrical energy. All these installations will, however, give a saving by making it possible to make fuller use of raw materials. Sulfur dioxide, for instance, that is at present ejected into the atmosphere could be utilized to increase the production of sulfuric acid several times. All possible efforts must be made to make the future air and water of our planet absolutely clean and harmless.

One of the major problems confronting mankind is that of making up the shortage of fresh water. The growing lack of drinking water will become a catastrophe within the next fifty years. Efforts are, of course, being made to solve the problem by creating new storage lakes, developing projects of diverting the water of northern rivers to the arid southern regions and so forth. To this end, industrial enterprises are being converted to fully closed cycles of technological processes. The same is done with regard to sewerage systems. Installations for desalting sea water relying for

their operation on atomic reactors and other sources of electrical energy have been set up in many parts of the world and, in particular, in the Soviet Union.

In the future, when the much greater amounts of energy are available, the installations for desalting sea water will be widely applied and, in any case, used extensively to irrigate large arid areas adjoining the coasts of seas and oceans (as, say, the western regions of North and South America, the northern regions of Australia, the North of Africa and the southern regions of the USSR bordering on the Black and Caspian seas). When the energy resources are hundreds of times greater than those at present, the desalting of sea and ocean water will be commonplace. This, naturally, will take up a significant part of the energy output of the world.

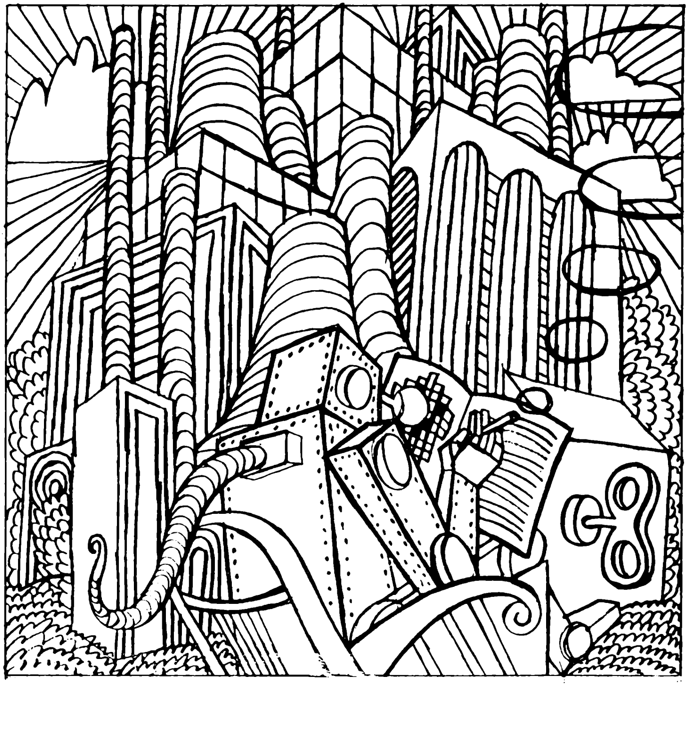
This brief and by far incomplete list of the needs of mankind makes it quite evident that it is quite possible to increase the output of energy by at least 20 to 40 times within the next hundred years in view of the expected 5-fold growth of the Earth's population in the course of that time. This requires, however, the combined efforts of all nations of the world.

All people must know and understand that their future and the future of coming generations depend on those efforts.

A STORY OF PRODUCTION IN THE YEAR 2000

AS TOLD BY A.E. KOBRINSKY AND N.E. KOBRINSKY

DOCTORS OF SCIENCES



Production is an all-embracing concept. It encompasses relations between people, between people and natural resources, between people and machines, and between machines.

Farming and mining, machining and assembly, development of new machines, materials or processes, quality control and standardization, warehousing and marketing, training and accident prevention, restoration and conservation of natural resources—each of these numerous facets gives a different picture of production. In socialist society, all of these facets serve the same common goal, that of satisfying to the maximum the continually growing material and spiritual demands of society members. The same goal is sought in the plans of the national economy, individual industries and factories. The strategy of economic growth and development, for which production is the basis, is embodied in long-term forecasts and plans, and its tactics in the daily operational management of each of its basic units that produce the material wealth around us.

Production is going on unceasingly day and night, turning out huge flows of things—tools of production and good things of life. These flows of ever new things are growing from day to day, and this circulation, picking up speed and accelerating all the time, is a distinction of socialist expanding production.

When you turn a tap in your kitchen, you produce water; when you turn the handle of a gas line, you produce gas to cook food. Water and gas, and also oil, petrol, fruit juice and mineral water are conveyed by pipes; pipes go into structures, and there is hardly a single machine that would not use pipes or tubes in one form or another.

How many such pipes and tubes do we need? Hundreds, thousands, tens of thousands?

No. The lowest minimum present-day production could not do without is about a million. Just imagine this number! A million of tubes and pipes made from different materials, in different diameters, and different wall thicknesses, and each grade, in Kozma Prutkov's words, "would only do good when used in the right place".

In the Soviet Union, there is a chain of stores called "A Thousand Gadgets". This name has been chosen to impress the prospective buyers with the range of goods available. However, the people who have invented the name have been wrong at least a hundred times. These stores are selling over a hundred thousand, and not a thousand, gadgets. But even this multitude of goods is only a small fraction of what production makes to satisfy the needs of today's consumer.

The language of numbers is dry and unfit to describe the beauty of nature or the emotions of a person. However, you must admit that you can hardly find a more impressive image for the wealth of things that man has put at his service than the multi-digit numbers giving a measure of his wealth. For the socialist production of the 70's, this measure is about twenty million different things, different in the actual meaning of the word, for there are no two things alike in properties, purpose, manufacturing methods, uses, and ability to satisfy the demands of society. As the economist, planner, product designer or production engineer would say, such is the range of products made and consumed in the Soviet Union. And any of these things, be it a tin can, a turboalternator, a newspaper, a TV receiver, a bicycle, or a supersonic airliner, is brought into being by the effort of man's brain and hands.

Yet, there was remote time when man could not even imagine he would ever invent a metal pipe, or the less distant time when he did not even think of a daily newspaper, or the more recent time when he did not suspect he would be able to preserve food.

You may ask why is all this talk about things of the past in an article projected into the future?

We have done so with the sole desire to bring out the driving forces knowledge of which will enable forecasts about production to be made with a minimum risk of wishful thinking and our phantasies to be built on the basis of reality. This basis is supplied by the forecasts and programs for the social and economic development of the Soviet Union up to the year 2000, drawn up by numerous teams of specialists equipped with an armory of present-day scientific techniques and engineering facilities. The forecasts are supplemented by the specific calculations for the individual industries and their advance towards the objectives set for the next 25 years.

What will production be like in, say, 50 years from now? Will the driving forces at work today remain the same? Will the trends underlying the forecasts up to the year 2000 be still in force or they will change drastically at the turn of the century? If they change, what technologies and techniques will be in use in the 21st century?

These questions are no empty curiosity or shear love of new knowledge.

However specific the time span covered by forecasts or programs may be, it is important always to remember that society will not cease to exist at the end of that period and that this period will to a great extent decide how society will develop next. In other words, the realization of the forecasts and plans for the next quarter of a century is of vital significance to the

progress of production in the twenty-five years that go next. This is why we must answer these questions already today.

Clearly, nobody is going to state in detail the technical and economic aspects of new manufacturing processes, new methods and means of process control, or ranges of products. But we may and, indeed, must picture to ourselves what production in the 21st century will be like, at least in a general outline, even letting our phantasies to play a little. Before we do so, it is important to carry to completion our talk about the driving forces of socialist production.

In fact, we have already named one of the driving forces—the continual desire of each person and of society as a whole for an ever wider diversity of good things of life. We may however ask if this principle is unavoidable and eternal? Should not we limit arbitrarily what might seem an "awful" and wasteful diversity to some law-defined, rigid and unchangeable minimum applicable to many years ahead, say, up to the year 2050?

It is obvious to anyone that this regimentation is unnatural and runs counter to man's character and his social organization. Man never ceases probing into things around and inside him. In their desire to extend the life span of human beings, physicians, biologists and biochemists are discovering the causes of more and more diseases and inventing new remedies. How should we then do? Suspend the production of new medicines, of new substances for them, and new machines for their manufacture until the year 2050?

Millions of cars are polluting the air in cities. How should we do—suspend work on new non-polluting vehicles until the year 2050? Not to produce new material and spiritual values and not to make their production possible in advance?

Of course, complete satisfaction of the continually growing demands of man does not exclude certain reasonable constraints on the range of consumers' goods and services, especially on those which can hardly be called "good things of life". The crux of the matter is what is the criterion of reasonable constraints. Although no one can answer this question once and for all, we may contend that narcotics and pornographic films will never be "good things of life". We also firmly believe that we shall always be able to choose a criterion of reasonableness for specific constraints. At its basis, however, the principle of a continually expanding diversity of good things of life will remain a major driving force in the economic life of society.

The second driving force behind progress in science and technology and the development of production is labour-saving.

When he took up a stick to knock down a fruit from a tall tree, the primitive man could tell his companions something like this:

"Ain't it a miracle—no tree climbing, no belly and leg scratching, no time wasting, no risk of falling down. With a stick, you do the trick in a thrice. That's what I call labour saving and efficiency!"

Of course, he could express himself altogether differently. Still, these things were in his mind when he took to picking his first tools. In the millennia that followed, man realized it was worth while spending some of his time and effort on making tools with which he could save labour enough and to spare. Many centuries later industrialization showed that it was much more advantageous to make machines that make tools. Today, we have reached a position where we begin by making machines that make machines that make tools. Production processes are becoming ever more indirect and therefore more efficient—a fact

which lies at the very basis of their intensification and, as a corollary, labour saving. This inevitably leads to a much wider variety of objects and tools of labour.

Thus, we have defined two "eternal" driving forces of production: increase in its diversity, including consumption, and saving of labour involved. How do we find their resultant force? How can we reconcile what appears as irreconcilable as fire and water?

There is only one way to tackle this crucial problem of social economy—by continually increasing the productivity of social labour, and by achieving a productivity where every unit of human labour can multiply public wealth at the most.

Now we have equipped ourselves with a reliable guide and can set out on our journey to the 21st century. It remains for us to select the point of departure or, rather, the first leg of our itinerary. Let it be the general trend in the progress of production which has already taken shape and been mapped out for the nearest decades to come. We may safely expect that this trend will continue into the more far-off decades.

* * *

It should be pointed out from the outset that no single book, let alone a single article, can cover to any exhaustive extent the huge variety of ideas, engineering approaches and manufacturing processes that make up the contents of what is defined as production today. The problem grows still more formidable when it comes to forecasting the future encompassing a considerable span of time such as is taken up in this book.

Any forecast or prediction is above all an extrapolation based on expert and sober estimates of what

has been in the past and what there is at present. However, this is no simple or, as it is technically put, linear extrapolation where you find what you are in for in the future by computation of some proportionality factors and direct multiplication.

At the beginning of the 20th century, the steam locomotive, wire telegraph, the electric motor, the pianola (a mechanical piano) and the simple adding machine were classed among the wonders of technology. Some of these miracles have already fallen out of use or are on their way there. You can no longer see belt transmissions at factories, a steam locomotive is now a rare sight on railways, and the mention of the pianola immediately brings in a request for an explanation, although this automatic instrument was a fairly common thing in the early years of this century.

Many of the miracles invented in the recent past are still in man's service. If we wished so, we could readily calculate how many times the length of telegraph lines, or the number of electric motors and adding machines has increased over the past quarter of a century and project their expansion into the future. Yet, however interesting such figures might be, they could not serve as a yardstick with which to measure progress in science and technology at present or, the less so, in the future.

Production, as we know it today, has grown on the fertile soil that was supplied by the engineering and technology of the past. Improvements in tools, invention and use of new machines, materials and processes have been going on at an ever increasing rate. Man has been accumulating ever new experience in scientific and technical creation. Every day and, indeed, every hour sees new ideas, methods and means sprouting in every field of production. These sprouts are still to make their way through the thicket of the

techniques and decisions that have now become traditional and common.

This is why he who wishes to figure out what production of the future will look like must be able already today to see all that is new or just taking shape in labs, in awkward prototypes or on "breadboards", and has little to do with actual production. Not only to see, but also to grasp its value and foretell the niche it is going to take up in the nearest and the more far-off future.

The frontier of progress in science and technology is so widespread and is rolling back at such a pace that there is no way or even sense to cover every of its segments, even though we take a single industry rather than production as a whole.

What we can do is to pick a major industry and to try and envisage its future and outline the main path this industry is following.

The core of large-scale machine-based production is machine-building as it supplies all the necessary tools and enables manufacturing processes to be carried out efficiently and at high productivity. Present-day trends in science and technology show that the mainstream trend in tool development is the consistent replacement of manually operated machines by automatic ones.

Thus, it is automated machine-based production and process automation that should provide a solid foundation for the society of the future. This brings us to one of the vital problems in the progress of science and technology.

Automation is the vital sector where the frontier of scientific and technological progress is being pushed back at an especially fast rate. It has already taken deep roots in a great many industries. Today we have automated electric power stations, oil refineries, che-

mical plants and departments. Several thousand automatic production lines have been put in operation in the USSR. Design work is under way on hundreds and even thousands of types and sizes of automatic machines and equipment to work metals, plastics and wood, to process food, to make medicines, cigarets, matches, household utencils—hundreds or even thousands of products in demand in an ever widening range in all fields of production and consumption.

What is important, however, is not so much to convince (ourselves and) the reader that the level of automation in production is continually rising, as to disclose the contradiction inherent in the process and to map out the course for present-day production to resolve it.

Tens of thousands of aspen and fir trees go to sawmills to be made into matches, and match-making factories ship car-loads of match-filled boxes daily.

The process starts where automatic machines cut logs into measured blocks, peel off them an endless band like a bandage with broad knives, level the band, and chop it into splints. The splints are then steeped in a solution so that matches would burn without smouldering. Next the soaked splints are dried, cleaned, shaped and sorted for rejects. Finally the splints are turned into matches.

Everything is done by automatic machines. By the time matches are finished, other automatic machines make and feed match boxes to a filling machine. Man's hand never touches a box of matches anywhere on its fairly long way of manufacture, which is also true of the loaves of bread coming from an automatic bakery, cartons of milk, and cans of preserved food.

Between raw materials and finished products there is a whole range of highly specialized automatic machines, lines and plant. Thanks to them, one kopek

can buy you an attractively styled box of a rather complex design (just take a closer look at it) filled with some fifty matches.

However, before an automated process can be utilized to advantage, it is necessary to build the complex structure that makes this process a reality. Of course, it is an easy matter to imagine highly specialized automatic factories turning out only automatic machines to make matches, other automatic factories producing automatic machines to make sausages, and still other automatic factories manufacturing automatic machines to make candies.

Unfortunately, this picture of machine-building is naive. Matches and bread, newspapers and books, textiles, nails and lamps are made in millions or even in thousand millions every year; these products are simple and change little, if at all for years or even decades. In the circumstances, it makes sense to build automatic lines, departments or factories to make them. In contrast, the machines and automatic plant involved are needed in thousands, hundreds, tens or even single units. Also, they are complex in design, use thousands of parts, become obsolescent quickly, and need updating continually. As a corollary, this calls for changes in their principle of operation, design and construction.

In fact, as automation gains more and more ground in various industries, an even wider range of machines, automatic lines, and plant is needed.

Obviously, it would be senseless to make highly specialized plant for their manufacture. Even if we tried to use conventional universal methods, facilities and techniques, the manufacture of automatic plant would swallow so much money, time and skilled labour that it would not be worth "powder and shot".

This is where large-scale automation runs into a

contradiction. There is only one way to resolve it. Mass products will continue to be made, as they are today, by high-speed automatic and automated manufactures based on principles which are becoming common and traditional. The plant for such manufactures, however, must be designed to embody novel, unorthodox methods and techniques.

These methods and techniques must be highly efficient whether they are used to make single parts, medium-sized batches or large quantities. They must be readily adaptable to a change of product or product design. These methods and techniques must combine the flexibility and adaptability of conventional multi-purpose plant, conventional lathes, milling, boring and other machines which need highly qualified workers to operate them, with the precision and productivity of automatic machines operating unattended.

Such methods and techniques have been developed over the past quarter of a century. They are known under the roof name of numerical control of machines.

A present-day numerically controlled machine follows a program stored on magnetic tape not unlike that used in tape recorders. As the program is read out, signals invisible to the eye go to control the motion of the cutting or milling tool, the slide and the blank. The separate motions are coordinated to machine the workpiece as required by the program.

Conventional multipurpose machine tools may be likened to a piano—it can play any piece of music provided there is a good pianist. Similarly, a lathe or a milling machine needs a qualified operator. A highly specialized automatic machine tool may be likened to a street organ, however well it may be built. It will play always the same tune. A numerically controlled machine is like a tape recorder—it only needs a tape-

recorded program. The machine will read it and automatically machine the part as told. Should we need a different part to be worked, it will be enough to load a different tape, chuck a new blank, and change the tool.

In fact, such an automatic machine embodies a good measure of the quality inherent in the combination of a multipurpose machine tool and a highly qualified machine operator—versatility. And its productivity is far more superior—it never grows tired, there is nothing to distract it, nor has it to change its habits or skills when told to machine a different part.

Numerical methods of machine control fit nicely the two principles formulated earlier. Apart from saving expensive manual labour, they help to satisfy the ever-growing demand for the diversification of engineering products dictated by the demand for diversity in consumer's goods.

Numerically controlled machine tools are inseparable from digital computers. Digital computers carry a lion's share of burden in preparing programs and make, in many cases, the very numerical control a workable scheme. Much as man has made conventional machine tools versatile, so digital computers have made universal the numerically controlled machines.

Work on computer-controlled machines started a quarter of a century ago. The first stage in their development was completed fifteen years or so ago. In 1960, there were not more than 200 to 300 computer-controlled machine tools the world over. In 1962, the United States had 1,500 such machines in operation; in 1964 their number rose to over 4,000, and in 1967 to 10,000. Today, over a quarter of all machine tools produced incorporate computer control systems. This picture of a large-scale expansion of numerical control applies not only to the United States

and the Soviet Union, but also to some other advanced nations. In fact, numerical control has been a major trend in scientific and technological progress over the past twenty five years. But, no matter how much has been done, it remains much more to do. We have only tapped the huge reserve of potentialities that numerical control methods carry with them. We may say with conviction that in the year 2000 engineers and technologists will look back on present-day numerically controlled machines and their present-day capabilities in much the same way as present-day car and airplane designers are looking back at the early cars and Wrights' aeroplane—with a warm but condescending smile.

The next quarter of a century will see, above all, a big quantitative jump in the manufacture of numerically controlled machines, an increase in their range of types and sizes. Among them will be machine tools of the machining-centre type fitted each with a complement of cutting tools, drill-bits, taps, reamers and the like, able to machine a blank without re-chucking it to any program prescribing tens of operations; high-precision, high-speed machine tools to make most intricate parts from light-weight alloys or high-alloy steels by machining, gas-cutting, pressing or extruding. In effect, some of these machines have already been developed and put in operation, and they will be turned out by thousands before long.

However, this quantitative jump, inevitable as it is, is not the whole story. What is more important is that digital control is taking over ever new segments of production.

The production process of an engineering works is much more than the machining of workpieces. It is a long chain of steps and operations including work on the process itself, the choice of optimal machining

parameters, assignment of machining allowances, inspection of blanks prior to machining, quality control of finished components, and assembly of end products.

Today, many of these steps and operations use human labour, of high skills and in large amounts. Before long, this labour will be replaced by systems based on digital control.

The few examples that follow have been chosen to demonstrate some of the new ideas currently under development, but soon to be used in mechanical engineering on a large scale.

* * *

Numerically controlled machines operate under programs drawn up by digital computers. However, data for programming are still supplied by man. The machine follows the same program on the first, second, third, or hundredth workpiece.

It is nice when the human programmer can draw up a program so that the machine can do its best as regards accuracy and output. It would be nice, too, if the programmer and the tool engineer knew how the machine, tool and work deform (and they do deform) in the course of machining. It would likewise be nice if they could foresee how the cutting, milling or other tool wears with time (and it does wear down). It would be nice if they knew how the machine parts build up heat in operation and how the deformation caused by this heat affects the product. Now, if they could foresee or know all these things and provide for them in the program, then the machine would work the tenth and the hundredth part in an equally optimal manner. Unfortunately, neither the tool engineer nor the programmer know these things today, nor will they know them tomorrow, nor probably in

the remote future. In fact, there is no special need for this, either.

So-called self-adjusting or adaptive control systems will be able to run machine tools in an optimal manner without human intervention. They will accumulate, process and utilize data in order to achieve the best results. Suitable transducers will gather information about the progress of machining, about deformations in the machine, tool and workpiece, about wear and tear on the cutting or milling tool, and about heat build-up in the entire system. Their signals will be processed by a computer or computers, and appropriate corrective actions will be initiated to adapt the original program handed down by the engineer to the changed conditions.

In other words, man will, as it were, set a goal for an automatic machine, and the machine will learn, all by itself, how to achieve it in the best possible manner with the aid of artificial senses and digital mechanisms. Only the first part will be machined to the program set in by man. From that instant on, the automatic machine will store up and go by its experience to streamline the program and work all the subsequent parts to the utmost in precision either at the highest rate or best economy.

Of course, the criterion to be used by the machine will be prescribed by man, but all steps involved in the search for, and adjustment to, an optimal execution of the program, everything that cannot possibly be done by traditional methods, universal machine tools and operators however skilful, will be carried out automatically to yield high precision, productivity and economy.

Early experiments on the design and use of adaptive systems for the numerical control of machines have already been made. They have shown that this new

type of equipment is extremely efficient. Undoubtedly, it will find a broad field of application in the future.

Now a part has been machined to a program. How can we make sure it has been worked correctly and departs in no way from the drawing produced by the designer?

Of course, when it is a simple shaft or washer, there is a simple way to do the job. If it is turned out in thousands, millions or even thousand millions, it will be enough to install specialized high-speed automatic checking machines; sometimes universal measuring tools will do.

But what if the part is an odd-shaped piece, or if it grows more and more varied, and the requirements for its precision become more stringent while the time alloted is cut down and instead of measuring two or three dimensions a complete picture of surface finish is needed?

Traditional methods of quality control based on templates, gauges, and highly qualified quality inspectors are wasteful of manual labour, time and money. On the other hand it would be as senseless to build specialized automatic machines to check the quality of such products, as it would be to build specialized automatic machine tools to make them.

The search for a way-out has led to a qualitatively new field in the use of numerical control—that of automatic gauging.

In the principle of operation, an automatic gauging machine is not unlike a numerically controlled machine tool. But instead of the work it mounts the finished part to be gauged, and instead of a cutting tool it uses gauging (or calipering) probes.

The product engineer marks in advance the areas to be gauged or calipered on the finished part, and the programmer draws up a suitable program. Then

the part to be gauged is set up in an automatic gauging machine, and the machine is started.

As it moves along the part, the gauging probe "senses" the surface. If the surface has not been machined as it should be, the gauging probe and, in its wake, all the other elements of the automatic quality inspector will register any departure. The same instant the gauging program is completed, the machine turns out a highly accurate record of what has been done or not done on the part.

The first numerically controlled gauging machines have already been put to work in industry. They can markedly cut down the time needed to control the quality of most elaborate products and exclude the "human element" along with its accompanying errors and reliance on gauges, templates or standards. Copies of quality-control programs may be circulated to many factories to ensure high uniformity and quality of products.

It is beyond any doubt that gauging machines will take up an important place in the numerical and digital control of machines in the engineering industries.

Thus, we have seen that numerical control systems can be fitted in a variety of machine tools, adaptive systems and gauging machines. It is not hard to guess that they can be used other than separately. They can be teamed into complete automatic lines and plants. Such automatic lines would differ qualitatively from the traditional ones intended for the mass production of repetitive products. A numerically controlled production line, much as each of its individual machine tools, will combine the versatility and adaptability of general-purpose plant with the precision and productivity of specialized automatic machines.

Experimental numerically controlled machine-tool lines have already been built. Obviously, they may

well be extended to include automatic gauging machines and adaptive control systems. This would raise the level of automation in the engineering industries and improve their efficiency and quality. Numerically controlled lines and complexes have good prospects of being incorporated in many engineering industries within the nearest twenty five years because this is dictated by the entire course of progress in science and technology.

Machining and gauging are not the only aspects of manufacture in engineering industries that a numerically controlled complex can cater for.

Imagine you are in, say, a car assembly shop (in fact, any other machine can be assembled there). The sight impresses you by the steady rate at which the process goes on—a car rolls off the line ever so many minutes to be followed by another car after exactly as many minutes, then by still another one, and so on. Unfortunately, the impression is somewhat spoiled by the monotony of the cars produced. The cars rolling off the line do not differ from one another in the least—in parts, colour scheme or options. This is because the assembly program has been set in to last a long time.

However, we may do away with the monotony by entrusting to a computer both the compilation of the assembly program and the execution of orders on cars. It is all the same to a computer whether to remember an order for one car or for a thousand. It can readily store all the options that a particular customer wishes to have in his future car. The remainder of the assembly process can likewise be steered by the computer. It will deliver to the assembly line a car body painted red, blue or whatever colour is specified, ordinary or tropical tyres, a standard-quality or top-class radio, and so on. Each of these parts will be installed

in a particular car ordered by a particular customer.

Here again, numerical and digital control follows the trend that leads to saving human labour and extending the diversity of products. The next 25 years will surely see a still wider use and development of these methods. And that will be no end to progress.

* * *

Participation of digital control in the assembly described above was limited to auxiliary operations such as control of the speed of the main assembly line and of the conveyors delivering car components—blue or red car bodies, ordinary or tropical tyres, etc. Assembly as such is however done by people. When a car body comes in, they drop it on a chassis and do a multitude of motions—fast or slow, sweeping or minute, involving force or not. When tyres arrive, another set of motions is needed.

People put together cars and aeroplanes, motor cycles and bicycles, radio and TV sets, and thousands of other machines, assemblies and systems. Literally millions of people are engaged in assembly operations. These operations seem to involve purely human motions and have not been practically automated. This is where we are wasting huge amounts of human labour. On assembly lines this labour is broken down into a multitude of highly differentiated steps. An assembly-man may perform an intricate motion, but as long as he is assigned to the same work station, he is forced to repeat this motion again and again. His job is repetitive and therefore uninteresting. It may well happen that some step requires a considerable physical effort; then the assembler's job is not only uninteresting, but also tiring.

Thus, assembly is a reserve for improvements in productivity and a wide field for the application of ideas and methods of automation. Have specialists not seen this?

Of course, they have, and they have consistently been looking for ways and means of solving the long-outstanding problem adequately.

Operators of lathes, milling and grinding machines are all people of high skills; their principal concern is with control of their machines so that they can turn out products of precise dimensions and at a high rate. At the same time, however, they have to chuck a blank on a machine and unchuck a finished part. Many of the blanks and parts tip scales at 10 to 50 kilograms and, if each is machined in a few minutes, their chucking and unchucking grows into a formidable problem.

The skilled labour of a machine operator can be saved by using a numerically controlled machine tool; that has already been pointed out. As we have already learned, a major trend in the automation of the engineering industries is to install numerically and digitally controlled machine tools, adaptive systems and automatic gauging machines. It has taken a quarter of a century for this trend to take shape and roots.

Not a word has so far been said of who is to run these highly sophisticated machine tools, gauging machines and lines. Who will chuck blanks, unchuck finished parts, transfer them from station to station, and pass through gauging machines? In a word, who is to serve this plant automated through the use of state-of-the-art digital controls? Today, this is done by people, and as the level of automation rises their job becomes progressively less interesting and more tiring. To this we should add the fact that the number of numerically controlled general-purpose machine

tools and other pieces of engineering plant is running into millions and the prospects are that it will double for some of them and increase ten-fold for others.

As with assembly operations, little has been done until quite recently to automate chucking of blanks and unchucking of finished parts. Why?

If we take a closer look, we shall discover that the outwardly simple steps made in chucking blanks and unchucking finished parts or in assembly involve intricate motions in space, varying considerably according to the shape and size of workpieces and from part to part.

In a forge-shop, parts are forged from white-hot blanks. Apart from high skills, the smith and his helpmate must be physically strong and enduring, even though the forging operation is done by a mechanical hammer. The heavy white-hot blank has to be grasped with tongs, placed on the anvil, and turned over under the hammer after each or several blows.

Parts are most often painted by spraying. To keep paint sprays out of his lungs, a painter has to wear a protective mask, and the painting room or shop has to be equipped with safety devices. All this is expensive and involved, while health hazard still remains there.

Thus, if we examine all basic and auxiliary operations in an engineering works (and we have agreed to limit ourselves to machine-building), we shall discover that despite the relatively high level of automation, this industry is still using huge amounts of human labour. This labour, if we may say so, is "stratified by skills". The smaller part related to making and maintaining the automated plant involves high skills, broad knowledge and creative approach. The greater part, however, which goes to serve and attend to what seems a highly mechanized and automated plant is basical-

ly manual labour. This labour reduces to seemingly simple motions repeated again and again, but the trouble with these simple motions is that they are "human motions" and can best be performed only by human hands. Automation in servicing the countless pieces of engineering and non-engineering equipment may be termed the automation of typically human motions. The problem has long become extremely urgent and given rise to a new field of engineering almost officially named robot engineering.

If automation and digital control are among the corner stones of scientific and technological progress in the 20th century, robot engineering and "robotization" are to become major trends in this progress for a much longer span of time.

We shall not dwell on all of the problem of robot engineering here. It will serve not only mechanical engineering, but also other industries, including nuclear space and deep-water. We shall only briefly describe so-called industrial robots, already at work at factories.

This class of machines has been developed primarily to copy the motions of human hands. Man's hand is a mechanism of extreme dexterity. Its distinction lies in the fact that it has been "designed" to perform a countless number of all kinds of motions rather than a single one. In this sense, it is a universal tool.

An industrial robot, too, has a mechanical hand which, although less dexterious than man's, can perform fairly elaborate, human-like motions.

Man's brain is a sort of computer with capabilities for control of the countless multitude of his hand's motions. An industrial robot, too, has a "brain", a program reader, which, although no match to man's brain, is powerful enough to make use of the mechan-

ical hand's capabilities. As with a numerically controlled machine tool, any program can be loaded into the robot's program reader, and its hand will obey this program to chuck blanks, unchuck finished parts, put the parts together into an assembly, paint the assembly, and do a great many other operations now being done by man.

Work on industrial robots began about a decade ago. Today, their production and use are on a steep rise. The governments, universities and firms in the United States, Japan and other advanced capitalist countries are planning to spend many thousand millions on robot engineering. Big impetus is being given to similar work in the Soviet Union and the other socialist countries. The experience gathered in using industrial robots to date has shown that these machines are highly efficient and promising.

For example, an automotive firm in the United States installed twenty three Unimate robots instead of 46 operators on a wheel assembly line (operating on a two-shift basis). After a year's trial, it was found that the actual profit had been in excess of the average value warranting the use of new technology.

Economists and sociologists have since long been studying the economic and social implications of automation in industry. Before long they will have to open a new chapter devoted to the economic and social after-effects of robotization as a higher form of automation. But already now we can say that wide use of robots greatly varying in application and skills promises not only a dramatic increase in labour productivity, but also a host of other qualitative changes in technological capabilities.

Since we have limited ourselves to machine-building, we shall briefly dwell only on one problem, that of integrated automation.

Program-controlled robots and the new generations of robots equipped with "senses" and run by electronic computers are a natural complement to numerically and computer controlled machine tools, production lines, gauging machines and adaptive systems. Together, they will make an integrated digital-control system. Such a system may cover machining, quality control, assembly and many other production operations coordinated and controlled by a large central control computer. Such a process control computer can execute control directly (direct digital control, or DDC), without the need to use intermediate media such as magnetic tape or punched cards.

In fact, an integrated DDC system can handle, and on a higher level at that, not only manufacturing as such, but also all matters related to business data processing and management. On this basis, wide vistas open up for the integration of individual productive units into large-scale management information systems. In this field, scientists and engineers will have enough work to do in the 21st century as well.

* * *

Of late, newspapers, popular-science books and scientific monographs have increasingly often been using acronyms like ADP (for 'automatic data processing'), PCC (for 'process control computer'), DDC (for 'direct digital control'), or MIS (for 'management information system'). Many people gather together at conferences and simposia to discuss the design and use of automatic control and management systems for individual factories, whole industries, or construction projects, and for scheduling and planning at different levels of the national economy.

In the Soviet Union, research and development work on process-control, business-data processing and management-information systems started recently, but it was given big momentum from the outset. Today, we have something to show for the effort put in.

Some 1600 process control and business-data processing systems were put in operation all over the country, and this is only the beginning of a mammoth project—the creation of a single nation-wide management information system which will amalgamate the process control and management information systems in the individual industries and at all levels of the national economy. Improvements in planning and management through the use of automatic systems and mathematical methods have been given high priority for the next few decades. This is only too natural, because management is bound to be a perfect match for production in everything.

Brute force or a stick is no good in "driving" a robot to do more or better work. Nor will it respond to a bonus or a reprimand—moral and economic incentives would be wasted on it. The tremendous capabilities built into an automatic worker can be utilized to the full only through a proper organization of the entire production process. And this is not at all easy to achieve because present-day production, especially in the engineering industries, involves an extremely great number of factors, both technical and economic, which are interrelated in a very ramified and intricate pattern.

The thousands of time-and-cost norms, materials, parts, products, and various pieces of machinery form a hierarchical structure which needs daily supervision, management and guidance. This above all calls for information—on the operations planned, the plans followed, the processes used, and the business transacted.

Every unit producing, distributing or consuming things generates data related to these processes and essential for their control and coordination. In this way, production generates flows of information which must be reliable and objective, go where it is needed at the right time, and be processed for the purposes of planning and management.

Any advance in technology inevitably entails further complexity in the organization and techniques of production, causes factories to expand and become more specialized, makes more complex the relations and connections between and within factories. Information is continually growing in amount and diversity, and so are the requirements for its quality and for the speed of data processing.

Let us picture a factory as a block diagram which shows the flows of information circulating within the factory and also to and from the external world. Of course, such a block diagram can give only a very simplified picture of the actual situation. This is because relations between the various departments, divisions and services within a factory are so complicated that no full description can be given of how the factory lives and works.

In a very general outline, we can single out three blocks on which the factory organization stands. These are the management block, MB, the production block, PB, and the engineering block, EB.

The MB receives information from the outside world, which includes plans from the industry's headquarters, contracts and orders, costs of materials and products, material allocations, and so on. Over the feedback paths, the same block receives results of production and economic analysis for the previous period. The MB also stores various norms and quotas, such as technico-economic indicators, man-hours al-

located per unit of product, quantity of materials and machine time to be used, etc. On the basis of this internal and external information, the MB draws up a plan in terms of product and costs, which defines the managerial strategy for the period planned. Finally, the MB prepares a detailed break-down of the plan, makes it known to the departments concerned, including the PB, the EB and auxiliary services, and supplies daily guidance in its realization. Behind the words "prepares a detailed break-down and makes it known" stands a hierarchical and ramified system of deliberation and decision-making likewise based on a huge amount of various information.

From the MB, information flows to the PB and the EB. Using this information, the PB directs and supervises the conversion of energy and materials into finished products. At the same time and over the feedback paths, the PB reports to the MB on the progress of manufacture and on any departures from the planned performance.

The PB's tactics must be such as to eliminate or minimize such departures in the best possible manner. Therefore, the incoming information must be not only accurate, but it should come in at the right time, because any delay may not only make it useless, but also impair the entire control process.

To see what can happen, put on a pair of headphones and speak into a microphone connected to them so that whatever you say comes back correctly but with a delay. Your own delayed words will immediately confuse you, and you will stop talking, embarrassed. The same is true of delays in the transmission of data from the PB to the MB, except that the management will not lose their capacity to talk at length about the troubles they have run into, but will lose the chance to prevent them.

In our block diagram, there ought to be one more flow of information—that from the MB to the industry's headquarters. This flow carries reports on the factory's activity and is used in drawing up plans for the industry and in operational control of the factory.

In turn, the industry's headquarters generates information which goes to the higher levels of the country's economic management and is used to draw up development plans for the economy as a whole and to formulate plan targets for the industry concerned.

Then there is the EB. In contrast to the PB, it handles scientific and technical information it receives from the outside and stores inside, rather than energy and materials. Every product that the EB turns out is information embodied in new product designs, new production methods and specifications.

The source data are converted to this product by means of information arriving from the MB over the closed loop formed by the forward and feedback information flows. Our mental diagram includes connections between the PB and the EB. Over one of them, the PB receives information (drawings, plans and specifications) necessary to make prototypes and to implement the new production methods. The reverse flow carries information about the manufacture and tests of new designs, the efficiency of new machines, and the productivity of new processes. In the EB, these data are compared with the design ones, and decisions are made to remove the discrepancies.

Such is, in a general outline, the structure and organization of information flows interconnecting the three component units of a factory and maintained so as to coordinate their activities.

Today, most factories are still using manual methods for business data acquisition and processing.

Because of this, there is excessive specialization in managerial work. Planning and management are broken down into limited operations often carried out with no tie-in by different executives receiving data from different sources. This partitioning of management has an adverse effect on the organization of information flows, and these often duplicate one another because the same data are accumulated and stored in different departments, and processed independently. This leads to the unnecessary increase in the amount of paperwork, introduces confusion, and overtaxes the managerial staff with unskilled and unnecessary work, as they have to copy and process the same items over and over again. Naturally, the quality and flexibility of management suffers, too.

Fortunately, these primitive methods of data processing are falling out of use and giving way to automatic management information systems which mark a new qualitative jump in production control.

The scheme we have just described will help you to get an insight into the principles that underlie the structure and operation of automatic management systems because the three production elements and relations between them will be present, in one form or another, in any factory run by an MIS.

* * *

Speaking of a management information system, we usually mean both its hardware and software, and also the people that do the actual management. Hence, an MIS is a man-machine system where decision-making is man's responsibility. This is why any MIS is an automated, rather than an automatic control system.

It is safe to argue that automation of production will never, or at least in the foreseeable future, reach a point where man will be completely ousted from this most vital sphere of his activities. For creative work and management relieved of purely technical duties such as collecting and processing data, will always remain man's privilege. Of course, as ways and means of management are improved and streamlined, as our insight into laws and mechanisms of management becomes ever deeper, intuition will be giving more and more ground to facts. It is not unlikely that a good many decisions related to management will be made by machine and not by man. Yet, man's experience and skills, his peculiar ability to think and work in terms of vaguely coached objectives and concepts, and his way of looking into the future will always remain the most valuable factors in decision-making for management in the most crucial situations.

We shall not discuss the delineation between what man and machine should do in an MIS, which is a very crucial problem in the design of cybernetic man-machine systems. Anyway, nobody would venture a guess about this delineation. Therefore, we shall only briefly outline the ideas and principles on which management information systems are developed and operated. Many of the things we are going to mention are still in the design stage, others are being discussed and nursed by scientists and research-and-development people. Yet, the hierarchy of management information systems in the Soviet Union has already taken a fairly definite shape, and we may therefore stretch our imagination a little on a real footing.

Let us go back to the block diagram we used to follow the exchange of information between the three blocks of a factory, and imagine how this exchange will take place under automatic management.

Here, the MB is replaced by an MIS built around an electronic digital computer. The reader knows, of course, how a digital computer is built and what makes it work. We may only add that the electronic computer has no rival in any branch of engineering as regards its expansion into literally all fields of man's endeavour and the impressive rise in its performance and capabilities. It is no coincidence that progress in computer engineering has come to be measured in terms of generations. It is less than a quarter-century since the first generation of computers made their appearance, but man is already using the third generation, and the fourth is round the corner.

In this short span of time, the speed of computers has increased more than 1000-fold, and the capacity of their working memory more than 100-fold. The total storage capacity of a third-generation computer is several hundred million numbers. In fact, a single computer today has enough storage capacity to keep data on the entire range of products turned out in the whole of the Soviet Union.

A third-generation computer is no longer a single machine—it is a system held together by common control. It operates by multiprogramming, which means that it can execute a number of different programs at a time; it can operate in real time, and it can converse with man. Owing to high speed, huge storage capacity, and a ramified system of peripherals capable of direct interaction with distant users, such a system has practically unlimited potentialities in making automatic all steps involved in data processing for industrial management.

Recently we have witnessed the appearance of the Unified Range of Electronic Computing Machines (called for short "ES EVM" in Russian), developed by teams of scientists and engineers from the socialist

countries under the auspices of the Mutual Economic Assistance Council. This range includes computers based on several standard sizes of hardware differing in capacity and application. In the decades to come, the biggest computers of the range and their improved modifications will be incorporated in automatic management systems.

Apart from a computer or computers, the hardware of a management information system includes data input/output, data preparation and communication facilities. A multitude of devices will automatically keep records of how many products have been turned out, for how long particular machines have worked, how much material has gone into these products, and many other data right at the place where a given manufacture takes place. Over communication links, this primary information duly reduced will go to a central processor for storage and processing. The lines and arrows we have used in our imaginary block diagram will materialize into a ramified network of automatic communication links protected against noise and any mutilation.

A major distinction of data processing in an MIS is that primary information is utilized in an optimal manner in order to derive all the necessary technical and economic indicators. No longer will there be duplicated information flows, repeated looping of the same data, partitioning and isolation between computational procedures.

Integrated data processing will supply all users with the necessary information derived from first-hand and reliable source data.

As in material production, automation of data processing by computers will combine both versatility and flexibility and will save labour in amounts increasing with the diversity of data needed.

It is clear, of course, that information, however complete and timely it may be, is only a nutrient for management. The main thing—decision making—starts after information has been received.

This has brought us to the most crucial and intricate aspect of any management information system—that of interaction between man and machine within its framework.

Management is a purposeful activity inevitably involving the choice of a single decision out of a multitude of alternatives. Automatic machine-tools can be set up in tens of different ways, production can be arranged in hundreds of various schemes, products can be shipped from suppliers to consumers over an astronomic number of routes. Some of these alternatives are poor, others are a bit better, still others are far more better, but there can only be one ensuring the best returns from production—the optimal alternative. What is an MIS to do in tackling this central problem of management?

As we have already noted, the final choice in decision making in the most crucial and critical situations will always be man's responsibility. But the MIS can give man valuable help during the preparatory steps, by comparing the alternatives under actual conditions of production. In effect, without the huge capabilities of the computer, no human team would ever be able to compare all alternatives that arise in economic planning and management and to select the best one. Thus, the principal objective for management information systems combining man's experience and skills in the best possible way with the extreme versatility and flexibility of the computer is to augment the public wealth created by every unit of human labour spent.

However, before this cooperation can be utilized to the full, we must overcome considerable difficulties,

and this has not yet been done in a good many cases. The principal difficulty lies in the formalization of management tasks, that is, in preparing a description in terms of equations and rules of logic, usually called a mathematical model. (For economic problems we may call it an economic mathematical model). It is only then that a problem can be presented to a computer—in contrast to man, it cannot handle vague ideas.

To build a mathematical model of a technico-economic process, we need a deep understanding of its mechanisms, we must isolate from the multitude of controlling factors the most decisive ones, trace relationships between them, and find efficient ways of controlling the process in a purposeful manner.

This is not enough, however. As noted more than once, production is multi-faceted and involves a multitude of interrelated processes. Therefore, a single model will not do—what we need is a whole range of mathematical models related to one another and giving an objective representation of reality.

Work on such models for all levels of production is under way in the Soviet Union and the other socialist countries, but it is still far from completion. In some fields of management, mathematics is making its first steps, and it will be able to win a strong foothold there only some time in the future.

Still, we may assert that the nearest decades will see remarkable success in the development and use of mathematical methods for production management. Its guarantee lies in the concern shown for this problem, an ever widening scale of training in economic cybernetics and management information systems, and the steady and creative advance of economic science.

This will contribute to the expansion and enrichment of software for management information systems.

The incorporation of management information systems in all divisions of the national economy and their coordination is a truly mammoth task superior to anything man has done in his history. This task will in all probability be fully achieved in the 21st century. The main job is still to be done.

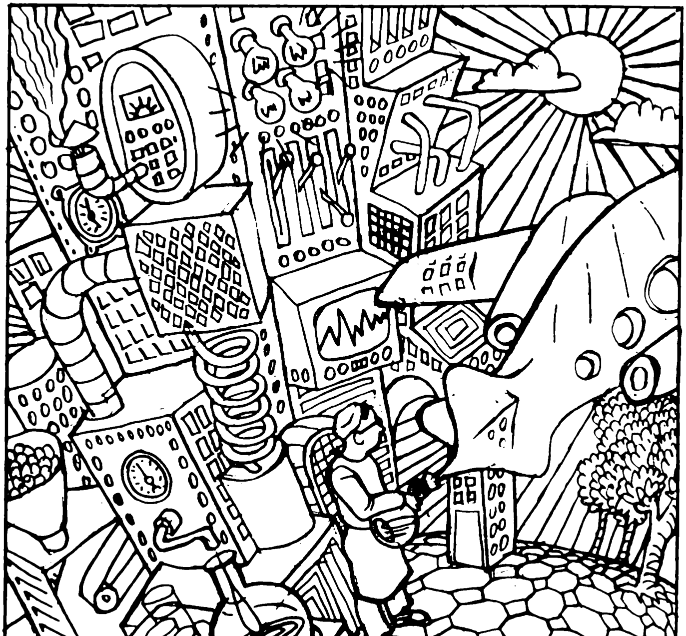
A STORY OF

FUTURE MAN-MADE OBJECTS AND ARTIFICIAL MATTER

AS TOLD BY

PROFESSOR

A.I. KITAIGORODSKY



Everyone of course would like to peer into the future. It is extremely interesting to make all kinds of predictions and it is only to be regretted that because of the short span of life the time in which we can check whether they are correct or not is limited to the beginning of the next century. How will people live in the remaining years of the XX century and the beginning of the coming XXI century?

An attempt to answer this question has been made by writers of science fiction and, recently, by many scientists as well. The former give free play to their imagination; the latter try to keep within the bounds of the laws of nature.

Conjectures about the more or less remote future (in which neither I nor you, my dear readers, will live) let us leave to the day-dreamers. As concerns the nearest decades, however, here a scientific approach is possible.

When reading novels, papers in periodic literature and scientific treatises, quasi-scientific reasoning and science fiction, it can readily be seen that they fall into three classes or categories. The first class comprises scientific predictions based on extrapolation of the known, present-day, state of affairs; their authors are scientists who specialize in prognostication. In the works of the second class, an attempt is made to look into the remote future without allowing for any changes in the state of science today; their authors are scientific workers who are not professional forecasters. And, finally, the few science-fiction novels where the authors do not confine themselves within the bounds of natural laws. The authors of these novels are usually professional writers, not scientists.

Now let us discuss the essence of the first approach to the future, i.e., extrapolation, with illustrations from the sphere of progress.

Extrapolation is a mathematical term and it means the following. If we are given a series of numbers 1, 3, 5, 7, 9, 11, what numbers will come next? We can answer "How should we know?"; but we can answer in a different way. "If the given sequence is retained, the next ones will be 13, 15, 17, etc.". That is what is meant by extrapolation which estimates the values beyond the known range on the basis of certain known variables. This method is used to predict the future on the basis of the study of the past.

This can best be demonstrated graphically. Let us, for example, lay off along the y-axis the annual population growth, the number of transocean telephone calls, the number of automobile accidents, the corn yield in millions of tons, etc., and along the x-axis, the time. Plot a curve by joining these points. The various lines will rise and sometimes fall at different rates or will fluctuate about a certain value. If we assume that variation in the values remains constant, the curves can be continued for future values.

This method can be verified by analyzing the past. The rate of variation is often characterized by the time in which a given value increases twofold or tenfold. It has been found that in a large number of cases, the time in which many factors determining the life of our society are doubled remains the same during a number of centuries.

One would think, for instance, that so much could occur all over the world that might hinder the growth of, say, scientific workers. All the casual circumstances, however, more or less cancel one another and, as a result, it so happened that the number of scientists in the USA beginning with the year 1800 has grown in the following manner: in 1800 there were 1,000 men of science; in 1850, ten times more, i.e., 10,000;

in 1900, 100,000 and in 1950, one million. That means that every fifty years the number of scientists increased tenfold.

Naturally, the first question to arise is how far ahead can a given function be extrapolated. It is obvious that those who make attempts at prophecy into the near future will make less mistakes than those who dare to foretell what will happen in the remote future, in many decades to come.

It is also true that the reliability of the predictions will be the greater, the longer a certain regularity has been observed in the past. If on taking ten balls out of a box, they all turned out to be white, it is likely that the eleventh one will also be white. In the event that 100 balls are all white, it would be very surprising if the 101st one turned out to be black. And if a million experiments gave identical results, a violation of the general rule would be nothing less than a miracle.

About the same holds true when predicting the future. Abrupt changes in the trend of a curve are improbable. A thoughtful researcher, however, should watch out for hardly noticeable signs of any variation in the rate of change.

Up to a certain time the number of cinema-goers grew steadily from year to year. But when television made its appearance and people preferred to enjoy a show in their own home, sitting in an arm-chair and sipping a cup of tea (or some other beverage), the number of cinema-goers first began to grow at a slower rate and then the curve bent and went downward. Could such a trend have been foreseen?

Without any doubt! Extrapolation does not consist in merely extending to a remote tomorrow a situation that exists today. If such an unsophisticated, mechanical approach were the essence of this method, it

would be too easy to foretell the future. Computers must be used in order to perceive initially imperceptible changes in the rate of increase of various vital factors. Only such an electronic machine is capable of rapidly correlating the enormous number of facts that are necessary for reliable extrapolation.

Prediction with the aid of technical equipment offers great possibilities. Demographic statistics (population statistics), the birth rate, for example, is influenced by a large number of factors such as the cultural level of a given country, its standard of living, its ideological aspirations. The greater the number of factors taken into account in the analysis, the greater the reliability of the forecast and the longer the time in which it will be valid.

In any case, however, there can be no question of hundreds of years. The invention of television and lasers, the discovery of nuclear energy, wars and revolutions can reduce to naught prophecies made by means of extrapolation. In the opinion of the author, scientific prediction is only possible for a period from 30 to 70 years.

Forecasts concerning changes in science, technology, art, medicine, morals, mode of living cannot be described by figures alone. The temptation to predict inventions and discoveries capable of completely altering the life of a society is very great.

Scientists, in contrast to writers of scientific fiction, believe that future events can be predicted only if they can be found in embryo in the present.

Not so long ago a prominent scientist in the field of prognostication wrote a paper in which he questioned whether the term "futurology" had any meaning. He claimed that, strictly speaking, a "science of prediction" does not exist because forecasts can be made with certainty only by experts in their particular field.

This, of course, is quite true. Yet, an "isolated prediction" does not make much sense because in our days the separate branches of science and technology are so intimately interwoven that it is absolutely necessary for someone to take upon himself the task of summing up the opinions of individual experts. The author of this article has no intentions to undertake this difficult job, but following the advice of the scientist cited above, will confine himself to a rather narrow range of problems, those constituting the subject under consideration.

* * *

What can prevent a novelist from imagining, on the one hand, a substance composed of atoms that instead of being attracted to other atoms in accordance with the law of universal gravitation are repelled by them. Such authors, on the other hand, can increase the force of cohesion between atoms, can compress them so that one cubic millimetre will weigh ten tons. A novelist can invent an atom capable of emitting "psy"-waves by means of which people even far apart can communicate with each other by telepathy.

The scientist, however, is a dry rationalist, cringing empiric, unimaginative futurologist, short-sighted and narrow-minded (these are the epithets that the writer Arthur Clarke uses to characterize men of science) and cannot allow himself to predict such startling things. The reason for this is the high regard he harbours for the laws of nature. The structure of matter at the temperatures and pressures under which we exist complies with the strict laws of quantum mechanics and statistical physics. The unexceptional realization of prophecies based on these laws

of nature, the fact that practically all modern civilization would collapse if these laws were not universal, are adequate grounds for the specialist in the field of the structure of matter to claim that, as concerns the creation of new materials, he knows with certainty the utmost possibilities latent in nature. Since this is so, he can tell us what properties of matter are possible and what properties are impossible because they contradict scientific knowledge once and for all confirmed theoretically and experimentally.

Prior to proceeding with predicting the future by extrapolation, I should like to remind the reader of some of the fundamentals of the structure of matter. For our purposes it is quite sufficient to call back to mind several postulates and laws. Concrete knowledge is not at all necessary. To be honest, the author himself cannot boast that he knows how the atoms are arranged in the mineral muscovite or in what sequence the particles are bound in alpha-naphthyl-methylene-imidazolin nitrate (drops used by those who have caught a cold).

We shall, therefore, merely touch upon the main ideas underlying the modern theory of the structure of matter.

First of all let us answer the rhetorical question: why is it impossible to play football on the slope of Mount Elbrus? The answer is: because the ball would roll down the slope. How long will it continue to roll? The answer is: until the ball falls into a deep hollow or hole in the ground; and if it evades such a fate, it will reach the valley.

A football obeys the law. It must come to rest in a position corresponding to its minimum energy. If the ball rolls to the foot of the hill, it will be in the most convenient position. It will not be able to roll out of the valley. This is called the stable state. Even

if the ball on its way down did get stuck in a rather deep hole, the wind or an earthquake in the vicinity of Mount Elbrus (no earthquakes occur there, I believe, but geographers will forgive me) could force it out of the state of apparent equilibrium (scientists have always had a weakness for using Greek and Latin words, therefore this is called the metastable state) and it would eventually roll down to the valley.

Atoms and the particles they are composed of, i.e., nuclei and electrons, behave in a similar way: they strive to occupy the most convenient position in relation to one another, one at which the bonding strength is minimal.

Now let us imagine that we are the primary creators of matter. We have at our disposal a gigantic reaction vessel. Let us fill it with milliards and milliards of atomic nuclei and electrons, taking care that there are an equal number of pluses (positive charges on the nuclei) and minuses (negative charges on the electrons). Our aim is to create electrostatically -neutral substances like all the objects surrounding us.

We shall then begin to lower the temperature in the vessel. The particles will move at a slower and slower rate and the nuclei will begin to attract electrons (minus and plus attract each other as you are sure to remember). The following variants are possible: the nucleus may take on the exact number of electrons needed to form a neutral atom; the nucleus may take on a number of electrons that is less than the "norm"—then a positive ion is formed; the nucleus may take on a number of electrons that is greater than the "norm"—then a negative ion will be formed. It can so happen that conditions will be favourable for some electrons not to become attached but to be used in common. Finally, it may be convenient for the nuclei to form microgroups in which part of the

electrons are shared among them. In this case molecules are formed. Thus, on lowering the temperature to a minimum we are likely to encounter the following kinds of solids.

The first kind: positive ions bound together by "unattached" electrons. These are called metals.

The second kind: spherical close-packed positive and negative ions; this can be imitated by packing billiard balls (negative ions) and filling in the empty spaces with ping-pong balls (positive ions). A large number of inorganic compounds are constructed in this way; silicates, for example. They are called ionic crystals.

There can also be groups of atoms having shared electrons; then it is said that the solid is composed of molecules. If the groups are relatively small, chemists call them low-molecular compounds. If, on the contrary, the atoms are joined in long chains or threads, they are called high-molecular compounds or macromolecules.

* * *

When compiling this small glossary of terms without which we could not proceed with the discussion in question, I used the word "crystal". The author knows from past experience that the word "crystal" is usually associated with something perfect and, therefore, rare. As a matter of fact the opposite is true. It is noncrystalline solids that are rare.

How can that be? Crystals have a perfect structure with undistorted crystal faces! That is why they can only be found in mineralogical museums!

But the contradiction vanishes with the aid of an ordinary microscope. It appears that solids consist as a rule of small grains (less than a micron in size) If such a grain be isolated and allowed to grow, it is pos-

sible (at least that is what is claimed by the enthusiastic specialists in the field of crystal growth working at the USSR Institute of Crystallography bearing the name of Academician A. Shubnikov) to obtain from any substance whatever a large crystal with faceted-like surfaces that are not inferior in beauty to sapphires and rubies.

What is the structure of a crystal?

Crystals consist of structural units (atoms or groups of atoms) arranged in a definite pattern like a fence, wall paper, honeycomb, like laid bricks. Metallic crystals consist of three-dimensional space-lattices immersed in an electron gas. An ionic crystal is a lattice made up of billiard balls and ping-pong balls. And, finally, molecular crystals are close-packed particles (groups of atoms) of quaint shapes that are regularly repeated in all directions.

A crystal is the symbol of ideal order, just as a gas is the symbol of chaos.

But, and this is of the utmost importance for our predictions, there is no such thing as ideal order in nature, and ideal crystals simply do not exist.

It is generally believed that Scotch tweed is the finest in the world. When I was lucky enough to find a length of such wool fabric, I would take it to my tailor Nikolay Vasilyevich and the following conversation would be held by us:

N. V. (with ardour). Yes, it cannot be denied that the fabric is of the highest quality.

I. A splendid suit could be made from it. The good material and your skill would guarantee that.

N. V. (without ardour). To tell the truth, devilish skill is required! The lines of the squares have to be carefully matched. When attaching the sleeves to the back of the jacket, for instance, no mistakes of even 1 mm are allowed.

I. (pleadingly). Please try, Nikolay Vasilyevich.

N. V. Well, it will not be for the first time.

And he always did manage to match the lines so that the squares produced a perfect pattern.

Nature does not attain the perfection Nikolay Vasilyevich does. When constructing three-dimensional lattices it frequently makes mistakes. There can be all kinds of defects in them—adjacent layers may be displaced, there may be voids, small cracks.

The existence of such defects in solids as well as the fact that they have a considerable effect on the use to which the solids can be put was established at the beginning of our century.

The strength of a material is one of its most important properties. When manufacturing any product it is always necessary to make sure that the metal, glass, brick or cloth will be strong enough, i.e., will not unexpectedly tear or break, jeopardizing the very life of people. And even if no such dramatic consequences occur, just the same who wants to deal with things that can fail you?

There probably is not a single factory or plant anywhere that does not test the strength of the starting materials, the intermediate and finished products. Usually the test piece in profile has the shape of the Roman numeral I. The bases of the numeral are clutched by claws of a tensile testing machine, the motor is switched on and the specimen is subjected to an increasing tensile pull in opposite directions until it fractures. A pointer indicates the increasing load—hundreds, thousands of kilograms—there is the sound of a crack and the specimen is broken into two parts. The number of kilograms divided by the original cross-sectional area of the test piece is called the tensile strength and the greater it is, the better the material.

For many decades efforts have been exerted to increase the strength of materials. Naturally, the more rapidly the population grows, the greater the significance of these efforts. As long as the number of thick-walled houses required by society was not very large such houses were built. There was no problem then of strength or of heat and sound insulation. In Kolomna which I visit from time to time, one can still stay at a hotel that was built a very long time ago. The rooms in it are like cells and are devoid of comfort and conveniences, but they have the advantage of absolute quiet, coolness in summer and warmth in winter. The secret is very simple: the walls are not less than 1 m thick and they will not crumble in the course of centuries.

In our times, however, this is sheer extravagance. Therefore, efforts are constantly exerted to increase the strength as well as the sound and heat insulation of thin walls.

There is no doubt whatever that a great deal has already been accomplished by these efforts, but we must also admit that the results achieved are not very imposing.

Why is this so? Why is an increase in strength of 10-20 per cent valued so highly? Is there no research capable of leading to a thousand-fold increase in strength? Is it not enough to appeal to physicists to find a way of increasing the bond between atoms? For, of course, that is essentially the problem. The greater the bond between atoms, the stronger the material; is it not so?

At the beginning of the century the eminent physicist, M. Born, calculated the strength of the bond between atoms. It is true that the theory was not developed for metals. The first substance to which the theory was applied was sodium chloride, i.e., table

salt. Salt was chosen because it consists of positive sodium ions and negative chlorine ions. These ions are attracted to each other in accordance with Coulomb's law (the reader surely remembers this simple law: the force of attraction is directly proportional to the product of the electric charges and inversely proportional to the square of the distance between them).

M. Born found a way of summing up the forces of attraction between all the pairs of particles, taking into account the repelling forces which arise when the atoms approach each other at short distances, and calculated theoretically the strength of table salt (by the way when salt is found in natural deposits and not in a saltcellar it is called rock salt).

Thus, a theory was found. It had to be verified. Large salt crystals are not a rare thing and it is quite easy to cut out test pieces resembling the Roman numeral "one". It only remained to insert it into a tensile testing machine and to watch the pointer to see at what point of the scale the specimen would fracture.

The test results were surprising. The values obtained experimentally differed from those predicted theoretically by an order of three. The calculated value was a thousand times greater than that registered by the testing machine.

Born's calculations are undoubtedly correct. Hence, the difference between the practical and theoretical results (between "practice" and "theory") had to be explained by a new idea which simultaneously came to several researchers, among them one of the founders of Soviet physics, Academician A. Ioffe.

M. Born's calculations were conducted for an ideal crystal lattice. But if it were assumed that in actual crystals there might be a great number of defects of all kinds, the bonding strength between atoms would be many times less than for ideal crystals.

A number of ingeneous experiments confirmed this assumption beyond any doubt. The famous "Ioffe experiment" for determining the tensile strength of a salt specimen in water is well known.

The scientist reasoned that water would dissolve the surface of the specimen and thus remove any surface cracks.

That is just what happened. A. Ioffe showed that the tensile strength was considerably increased when salt specimens were immersed in water.

In the last decades it has become clear that the efforts to increase strength should be exerted not in increasing the attraction between atoms but rather in decreasing the number of internal defects in crystal lattices.

That is what lies at the bottom of the idea of creating strong materials. The crystalline grain must be small and individual grains should be bound by an amorphous, glass-like interlayer. The chances are high that greater strength can be attained by combining grains of various shapes and mechanical properties, say brittle and hard grains with plastic ones.

It can be assumed that the future success lies in combining metals and ceramics; below we shall speak of this in detail.

Thus extrapolation into the future has led to the following conclusion: since it is impossible to increase the attraction between atoms, it is necessary to strive to improve the microstructure of materials, to create minute grains free of defects and to learn how to bind them strongly by means of an intercrystalline layer that is also free of defects.

The production of crystals without defects is quite possible. Recently physicists have learned how to obtain extremely fine crystals that are practically flawless. The strength of the fine crystals reaches the theo-

retical value calculated by M. Born. We believe that it is hardly probable that large crystals of this kind will be obtained in the near future. But this can be done without; minute crystals free of defects can be an excellent basis for creating materials of high strength.

* * *

Looking into the hazy distant future of technical progress, while holding fast to the Ariadne thread of extrapolation, two roads are visible, travelling along which man will obtain substances required to satisfy his needs.

On the first road an attempt is made to harness to one cart a horse and a deer, i.e., to combine materials. Already fine crystals of niobium carbide have been produced and implanted in metallic niobium. The electrical properties of niobium are excellent but its strength is very low. The material composed of niobium carbide combined with niobium retains only the good qualities of the constituents.

Practical use has been found for very fine threads of boron immersed in fused aluminium. In this case the light weight of aluminium and the strength of boron are united to form a new very light and strong material.

However, those who predict this way of creating new materials cannot claim that it is original. This, as a matter of fact, is the way long followed by nature itself. Indeed what is wood? It is a combined material made up of threads of cellulose in a matrix of lignin. That is how nature united the strength of one component and the flexibility of the other.

That is why the majority of researchers devising new materials and dreaming of obtaining a material that would be strong, light and resistant to attack by

corrosion take the road of creating all kinds of compound systems.

It should be noted that only the first steps have been taken along this road. Following the inclusion of glass threads in rubber there will appear thousands of new similar combinations.

How many centuries can iron and steel be employed? It cannot be denied that their strength is beyond criticism. They are, however, heavy and cast iron is, in addition, brittle. In the future these hard workers will give up their place to combined materials. Perhaps they will be replaced by aluminium, boron or magnesium containing fine flawless crystals of iron or cobalt. It would be still better to overcome the brittleness of ceramics. It is not improbable that there may appear materials consisting of ceramic or glass grains separated from one another by very fine metal films.

Of course, the combination of various substances with different properties is the way that will be taken by those who wish to obtain transparent materials possessing magnetic properties or transparent rubber, or light elastic fabrics with good anticreasing properties (in this case transparency can be done without).

Widely diverse methods will be used for combining various substances depending on the ultimate end in view. All the methods are already familiar ones. The first one is to mix the atoms or molecules of different substances. No patent, however, will be issued for this idea because this way of composing mixtures has been practiced for thousands of years and is known as fusion or alloying.

Surface coating is also a method known for a long time. That is however nothing to get upset about for instead of coating a base metal with chromium or nickel, the inventor can propose to coat any substance with any other one.

Neither is the idea of intermixing small grains of different materials new. The introduction of threads into a plastic matrix is a more recent idea.

Considering the large number of substances with different desirable properties at the disposal of mankind, it is not so hard to understand that the number of mixtures and combinations for which use has been found up to now is only an infinitesimal part of the number that can still be devised. Thus, the number of patents that will be issued for new combined materials will grow in geometric progression for many years to come.

The course of creating combined materials in which the hardness of diamonds, the elasticity of rubber, the transparency of cut glass, the conductivity of copper, the magnetic properties of iron and the light weight of aluminium are united is, in our opinion, the highway of technological advancement.

* * *

There is yet another course; it is not even a road but a path and physicists, not technologists, take this path. We are alluding to ways of changing the forces of interaction between the atoms of one and the same substance.

The properties of solids are determined by the nature of the bond between the atoms of which it is composed. These bonds, as described above, can be forces of electrical attraction or repulsion as in ionic crystals; they may be the forces that arise when ionic residues are bound by an electron gas as in metals; they may be valency bonds between atoms.

The weakest bonds are those between molecules. If a solid is built up of molecules, it is very easy to destroy it. A good example is naphthalene which "eva-

porates" at room temperature. The strongest solids are those whose atoms are joined by valency bonds. Such is the diamond—the symbol of hardness.

Is it possible to substitute weak bonds by strong ones? Theoretically (and if theoretically, then perhaps practically also) this is possible.

It is well known that there may be various modifications of a substance. The transparent and hard diamond and the black graphite that soils one's hand are constructed from the same carbon atoms. Yellow and red sulphur differ greatly in their properties, while five kinds of phosphorus are known to exist. When water freezes, its molecules arrange themselves in six different ways.

In the Soviet Union a method has been found for producing artificial diamonds from cheap graphite by changing the character of the interatomic bonds. Thus, the atoms of various elements can be made to combine in different ways.

For instance, there is still another modification of carbon that may be of great significance in the future.

In the diamond every atom extends four "arms" to its neighbours. In this way there is formed a three-dimensional structure in which the atoms are joined solely by valency bonds. Nothing stronger can be conceived.

In graphite each atom is united by valency bonds to three neighbouring ones, thus forming layers of atoms. How do such layers behave? They are attracted to each other by the weakest forces—like those in naphthalene crystals. That is why graphite is a good lubricant and is used for making pencils: the layers slide over each other when the slightest force is exerted.

From carbon atoms, however, it is also possible to form chains. Part of the atoms in such chains will have only bivalent neighbours. Such a material already

exists in the form of threads of amazing strength. Unlike the well-known capron, nylon and polyethylene they can withstand extremely high temperatures without being destroyed. Researchers expect very much from these threads. By combining them with light plastic materials they hope to obtain light, strong and plastic structural materials suitable for manufacturing miscellaneous apparatus and instruments and even extraordinarily light airplanes. And although about twenty years will pass before unambiguous test results are obtained, nevertheless investigations should be conducted tirelessly.

The nature of the bond between atoms fundamentally affects the properties of the substances composed of the atoms. The gas oxygen which we breathe is composed of bivalent molecules but there is nothing inconsistent with natural laws in assuming the possibility of synthesizing cyclic oxygen molecules consisting, say, of six or even sixteen atoms. Such a substance would be a liquid and could be poured into a bottle and taken by a mountain climber to the camp on Mount Everest.

Scientific fantasy permits the assumption that a "spark" could be found, capable of converting the cyclic molecules into bivalent ones, i.e., such molecules as those of which the oxygen we breathe is composed. This would solve the problem of oxygen deficiency.

The creation of relatively unstable atomic systems (recall our comparison of an unstable molecule with a ball that has become stuck in a hole on its way down to the valley) is a very fascinating problem for physicists. The principal methods for obtaining liquid oxygen, metallic hydrogen, sulphur as hard as diamonds and the like will probably be those based on the use of ultra-high pressures and strong electromagnetic fields.

Unstable atomic structures can exist for very different periods of time depending, mainly, on the pressure and temperature. At room temperatures tin can be white and grey. The two kinds of tin have different properties and, certainly, different structures, but at low temperatures an allotropic transformation takes place as was discovered to their grief by the members of Scott's polar expedition. Vessels soldered with tin disintegrated during severe frosts. The "tin pest" (this is the name for the conversion of grey tin to white tin) played a fatal trick on them. At room temperature this conversion takes place extremely slowly; but the lower the temperature, the more rapidly it develops and at very low temperatures it occurs instantaneously.

Thus, materials composed of the same atoms and molecules but of various structures behave differently. There is still a great deal of work to be done by physicists who are seeking "holes" for one and the same substance.

* * *

Every decade marks great progress in the creation of new materials with remarkable magnetic properties. One of these properties, magnetic permeability, is being improved at a rapid rate. I believe the value of this property that is so important for industry is doubled every five years.

The magnetic properties of materials are characterized by the so-called magnetic hysteresis loop which is described in any course of physics. Physicists connected with engineering are interested in the length and breadth of the loop.

By varying them the physicist strives to attain two ends: first of all, that the field in the blank space of

a horseshoe magnet should be the same at all points; secondly, that the field should be a strong one.

It cannot be said that there are still many means in reserve for attaining these results. Researchers are already on the brink of parallelly arranging the "magnetic needles" of all the atoms in the cobalt, iron, nickel and manganese alloys. Then a permanent magnet of the highest strength would be obtained. Theoretical calculations, however, show that even in this case the magnet will not be so very strong. What is needed for greater strength is an electromagnet, i.e., a magnetic core with a coil through which a current is passed.

Yet, even if they are not very strong, permanent magnets are needed in various fields of engineering. It should be remembered, for instance, that the quality of microphones depends on the quality of the magnets.

So far all this is familiar to the reader; therefore, it is worth while to speak of one line of scientific research concerned with the improvement of the quality of magnets, which the reader may not have heard about. Large magnets of high quality, weighing many tons, are required for nuclear magnetic resonance (NMR). What is this and what is it needed for?

NMR is an effective means of studying the structure of matter. If a very strong and uniform magnet were created, it would be possible within a minute to disclose the structure of the molecule of a substance and to depict on a screen the consecutive order in which the atoms in it are bound to one another. The essence of this method lies in the following.

Most atomic nuclei (N) have a magnetic moment, i.e., behave like a magnetic needle (M). Depending on the environment of the atom, the "magnetic needle" of its nucleus is protected differently against the

action of the field of the large magnet we are speaking about. This means that different nuclei are surrounded by their own magnetic fields that vary from one another. Let us, mentally, conduct an experiment.

On a substance under test in the blank space of a horseshoe magnet let us impose a radio-frequency field and begin to vary the frequency (this is called scanning). All the "magnetic needles" of the atomic nuclei vibrate at their own frequency depending on their own fields. When the frequency of the external field coincides with the frequency of the nuclear "needle", there arises resonance absorption (R). In each atom absorption occurs at its own frequency which can be registered by suitable instruments. Hence, all atoms can be identified if the variation in frequency of the external field is known.

So, as we see, good strong magnets are very useful, but natural magnets are incapable of producing a strong magnetic field. What is needed for this purpose are electromagnets with coils having no resistance to the flow of current, i.e., possessing superconductivity.

* * *

Many readers, of course, have heard of superconductivity. This phenomenon was discovered many tens of years ago, but the reason why there is no resistance to the flow of an electric current in a wire at extremely low temperatures has been explained only recently. The theory developed was not based on any new principles, but was founded on the laws of quantum mechanics which, as is known, were discovered in 1926. The logical path that led from the general law to the concrete phenomenon of superconductivity, however, was densely overgrown with weeds. Although many brilliant minds devoted themselves to the study of

superconductivity, the theory explaining it was finally discovered after more than thirty years of untiring search. The American physicists Bardeen and Cooper who were rewarded the Nobel Prize for their theory of superconductivity are very talented scientists and it would be unfair to say that they were simply lucky. Nevertheless, it should not be forgotten that the work of many scientists paved the way to their success (it is hard, for instance, to overvalue the contribution to the problem of superconductivity made by the Soviet physicists L. Landau, N. Bogolyubov, V. Ginzburg). To continue our analogy with a path hidden from sight by weeds, it can be said that the researchers engaged in solving this problem prior to Bardeen and Cooper discovered several disconnected sections of the path and it fell to the lot of the future laureates to unite these separate sections into one road.

The fact that the development of the theory of superconductivity proved to be so complex and demanded the efforts of a whole generation of scientists goes to show that it would be quite difficult to explain the theory in this paper. Besides, the theory cannot be said to be completed as yet. It is still incapable of giving engineers any concrete recommendations for imparting this property to conductors at room temperatures.

Efforts are being constantly exerted to raise the temperature at which superconductivity occurs. The results, to be true, are not very great as yet—minus 250 degrees is the record temperature. Thus, we see that for practical purposes not so much is left to be done—only to raise the temperature at least by 300 degrees!

Theoreticians are busy seeking systems that would possess superconductivity at room temperature. There is an immature idea that such a system can be a

"sandwich"—a material consisting of alternate layers of molecules of a dielectric and a conductor.

Is it necessary to emphasize the great importance of the search for superconductors working at ordinary temperatures? The colossal saving in costs resulting from the transmission of energy by wires is evident to anyone!

It is also worth while to consider another thing. Mankind is sick of exhaust gas. Gasoline and diesel engines can lead to no good. In Tokyo traffic controllers on duty wear gas masks. In large cities people literally gasp for breath. No wonder Japan, a densely populated and highly industrial country, is developing the idea of magnetic transport, utilizing even existing superconductors that work only at the temperature of liquid helium. The Japanese believe that despite the enormous cost of a tunnel in a stream of liquid helium, it is worth while tackling this job. What principle underlies "magnetic" transport?

The principle is well known. Electromagnets spaced at definite distances transfer ("throw") a small car from one magnet to another. After passing one magnet, the car moves forwards and just a little downwards due to the forces of inertia and gravity. Then it is caught up by the second magnet. It is true that the car will move along a slightly curved line, but that would not discomfort the passenger very much. In the opinion of the Japanese the high speed and the absence, virtually, of energy consumption will be worth the cost of maintaining the extremely low temperature of minus 270 degrees.

It is thus obvious that the discovery of superconductors working at ordinary temperatures would not only bring about a revolution in the technique of electroconductivity but it would also bring about a revolution in transport.

Superconductivity is to a great extent only a dream as yet. And notwithstanding the fantastic future promised by it, much less is being done in this field than in that of perfecting semiconductors.

* * *

The creation of new semiconductors is still given much attention. Researchers are at work improving the properties of such semiconductors as silicon and germanium as well as investigating the fields of conducting alloys such as gallium arsenide. It might seem that, as concerns silicon, there was nothing for the researcher to do. Silicon is, all in all, silicon!

It appears, however, that the semiconducting properties of materials are sensitive to a great number of factors. They can be substantially affected by the smallest defects, the slightest traces of impurities. So that many pages of scientific and technical journals are still devoted to investigations of materials that have long been known.

The search for better semiconductors is carried out mainly with the aim of miniaturization. Even our youngest reader has been an eyewitness to the striking decrease in size of radio receivers and tape recorders. There are already on sale pocket computers, as yet of course, of a limited capacity.

With the perfection of semiconductors, computers will appear in every library and then in our homes, side by side with the television set and refrigerator. By the way, the creation of large crystals of superconductors will make it possible to produce flat, nonvacuum television sets which could be hung on the wall just like a picture.

Individual radio stations will appear in the near future; this will make it possible to communicate with

an acquaintance wherever he or she might be—in India or Australia. And the time when this will be achieved is not far distant. In some countries "talky-walkies" are already available. They consist of two small transmitter-receivers tuned to one wave. When gathering mushrooms in the woods with a friend you need have no fear of losing each other. And in a large department store you would know that your girl friend is in the department for ready-made dresses while you are selecting a fishing rod.

* * *

We live at a time of rapid scientific and technological progress. Of course, as was correctly noted in a popular-scientific novel "not all progress is progressive".

This should never be forgotten when plotting the synthesis of new materials.

As has already been stated above, modern physics can predict the ultimate properties of materials. There can be no substance stronger than a flawless diamond crystal. The intensity of magnetization depends on the number of atoms per unit volume and will have the maximum value if all the "magnetic needles" of all the atoms point in one direction. The resistance to the flow of an electric current can be practically reduced to zero by lowering the temperature.

Science not only points out the courses that must be pursued to achieve important ends. It also helps to discern blind alleys; examples can be given of what cannot be attained because of inconsistency with scientific laws. It is impossible, for example, to create a thin thread capable of pulling out a truck stuck in the mud or a gaugy material capable of protecting the body from the cold.

Thus, nature itself sets the limits of what is possible and what is impossible, but these limits do not in the least hinder us from creating a world that suits us. The limits set by nature are nothing to be upset about. A reader who acknowledges no limits to the daring of man's ideas can ask what of new atoms will be discovered?

That could not occur. All the places in Mendeleev's table are occupied and all stable atoms possessing a lifetime long enough to enable them to be employed in industry have already been discovered. The appearance of a new stable atom would signify complete bankruptcy of the periodic law of Mendeleev and the equations of quantum mechanics. That will never happen.

However new molecules will be found?!

Without doubt, and here the reader can give free rein to his fantasy. He has at his disposal the hundred elements in Mendeleev's table and no one has the right to question the possibility of obtaining the most astonishing atomic structures.

How about the laws of valency?

Indeed, as a rule, the simple valency laws we all learn at school are infallible. Carbon can be joined with two, three or four atoms; oxygen, with one or two atoms; hydrogen only with one atom, etc. In recent years, however, chemists have synthesized a large number of interesting "freaks" that go to show that the valency rules are not absolute ones. A molecule can have any structure whatever, providing the electrons and nuclei of which it is composed have a configuration analogous to a deep enough hole on the slope of a hill (please reread the place above where we spoke about football on the slope of Mount Elbrus).

Chemists were completely astonished by the discovery of ferrocene. It was found that not only indi-

vidual atoms could be united by valency bonds but also the "centres" of groups of atoms as well.

The discovery of a family of molecules parts of which are held together without valency bonds was indeed a great event. These molecules are known as catenanes and they resemble in structure ordinary chains: rings of valency-bonded atoms linked to each other in a chain. In the future, two-dimensional and three-dimensional networks will probably be created in this way too.

As yet such substances have been obtained in very minute quantities and the rings are formed only by carbon atoms. Theoretically, catenanes containing nitrogen, oxygen, sulphur, and phosphorus atoms are also possible. If the problem of producing such materials were solved on an industrial scale, we would be able to obtain fabrics of any colour, of maximum strength and ideal elasticity, i.e., fabrics that do not crease at all and which are impossible to tear. So you see there is much to dream of without violating the laws of nature.

A sensation was created when compounds of the rare gases were obtained. According to valency rules they should not form any substances. It was believed that since in Mendeleev's table these atoms (argon, neon, etc.) have a valency of zero, their atoms could not form stable molecules with the atoms of other elements. That is why they are called rare or inert gases.

In accordance with what has been said above, molecules can be invented in which carbon will seem to have a valency of five; phosphorus, a valency of eight and sulphur is joined with three neighbours. This does not contradict the laws of nature. And how about the rules of valency?

Well, as with strict laws, we must say farewell to them but they should retain our deepest respect because the overwhelming majority of chemical compounds obey these rules unfailingly.

Aha, our opponent will exclaim triumphantly; this means that molecules of the most unexpected structures will be synthesized! Why then can we not assume that compounds can be obtained with properties surpassing the fantasy of today's sceptical scientist?

Because whatever the structure of the new molecules, no matter how strange it may be, the forces of attraction and repulsion between them will obey known laws. And the properties of materials are in essence the result of intermolecular and interatomic forces. Hence, no atomic structures will lead us to kevorit or to emitters of telepathic "psy"-waves.

But there is nothing to get upset about. The synthesis of new molecules will bring us many new marvellous materials not in the least less romantic than antigravitational matter that has caught the fancy of so many journalists.

"You simply want to 'sugar the pill' ", the opponent will claim sullenly. "You yourself have just said that the laws of atomic interaction cannot be changed".

Yes, I did say so. A little scepticism is not out of place. New substances that are very much needed by mankind are sure to be synthesized. It is necessary, however, knowing the ultimate properties of matter, to direct the synthesis of new materials along a definite course, in other words, to plan scientific research.

Millions of substances have already been synthesized. This work can be continued to infinity. But one's eyes should not be shut to the fact that a considerable number of the new compounds synthesized by chemists can fill only very small test tubes that peacefully rest on the shelves of cabinets.

There is no doubt that the time when any new synthesis was of interest because of the new way in which the atoms were combined in it has come to an end. No practical use has been found for the above-mentioned ferrocene and is not likely to be found in the future. It was important, however, to discover that valency bonds can unite not only atoms but groups of atoms as well. Such knowledge will prove to be useful to the chemist who will undertake the synthesis of new materials for some practical purpose.

Let us now speak of the synthesis of macromolecules.

* * *

Macromolecules are simply large molecules. There is no sense in debating the question of what is the minimum number of atoms needed to make up a large molecule just as it is useless to state the exact number of hairs on the head that distinguishes a bald-headed man from a youth with a copious head of hair. In any case, when there are thousands of atoms in a molecule, the latter is called a macromolecule. The largest macromolecules can be hundredths of a micron in size (in the world of atoms this is as large as Cheop's pyramid).

In this case the laws of logic may also be the basis for making conclusions concerning the synthesis of all kinds of macromolecules. Large molecules can be made up of similar units or of different ones. Individual links can form linear chains, two-dimensional networks and also three-dimensional skeletons. It is harder to find a construction that would be impossible than one, no matter how incredible, that could actually be realized.

Macromolecules are found in nature and are produced in laboratories and chemical plants. It has long

been known to chemists that the molecules of cellulose, rubber and proteins consist of many thousands of atoms. And for a long time artificial macromolecules were looked upon as wastes which must be discarded (poured down the drain). In the 40's, however, the state of affairs was changed. Nylon, capron, polyethylene and other synthetic polymers put in their appearance.

Any polymeric molecule is a macromolecule, but not every macromolecule is a polymer. The prefix "poly" which signifies "many" speaks for itself. Polymeric molecules are those consisting of recurring units. The molecules of nylon can be visualized as a string of identical beads.

For a long time the synthesis of polymeric molecules consisted in creating conditions for joining one bead to another in any way at all. What is meant by any way?

Let us imagine that the bead is not round but oval in shape. Then a chain can be formed from beads strung on a thread all in the same position (say, all the beads are strung on the thread so that their long axis coincides with that of the string or on the contrary is perpendicular to it). At first, how the beads were strung was left to chance (one along the axis of the molecule, another perpendicular to it, a third one at an angle to it). Later, however, a method was found for obtaining oriented molecules. As a result, the mechanical properties of synthetic materials were substantially improved (for instance, stockings did not tear so readily).

The main trend in the chemistry of large molecules, I believe, is the tendency towards oriented, programmed, automatic synthesis of long molecules. Ideally, the synthesis of macromolecules of a new desired substance could be conducted as follows. Par

ticles of *A*, *B*, *C*, *D* are thrown into a reaction vessel; a program for the structure of the desired molecule is then plotted, for example, *AC*, *ACD*, *BACDABCADCADADABCA*. The apparatus is switched on and the synthesis proceeds by itself. The laurels claimed by Arthur Clarke, the unrestrained dreamer, do not interest me and I shall refrain from naming the exact year or even decade when such a programme will be realized. But I think it will be quite soon.

It is easy to see that the number of new molecules which can be synthesized is practically unlimited. Perhaps a time will come when the production of new molecules will be looked upon as something like a game of chess. The winner, say, will be the chemist who creates the most stable molecule consisting of one "king", one "queen" and eight "pawns".

There is no sense probably in assuming that mankind will continue to create new substances without an end. Synthesis of macromolecules will be conducted as long as this is practically worth while. It should be noted that there are no grounds for expecting any very big changes in the field of synthetic fabrics, for example. Of course, stockings, pullovers, trousers made of perlon, dacron, crimplen are improved from year to year, not to the extent, however, that we would like them to; and what is of most interest, cotton, silk and wool remain unrivalled. Perhaps the future of macromolecular chemistry lies elsewhere? Maybe in the perfection of technological processes?

Certainly, there is still much to be done by technologists engaged in the production of various oils, admixtures, coatings, substitute materials, metals. Just the same I doubt whether their efforts will lead to any revolutionizing innovations. Honestly, I do not believe that the need for new fabrics, new building materials is so great after all. After thinking it over,

it can be concluded that science and technology have given mankind everything it needs for a life of comfort and pleasure.

But there is one branch of science that is still in the embryonic stage. What I have in mind is biology.

To argue that mankind is desperately in need of an understanding of the laws of biology is equivalent to forcing an open door. That is why I think that in the future macromolecular chemistry will devote itself to biology. Mankind has come very close to the production of living matter. The "very little" that must yet be attained is to learn how to synthesize the "blocks" from which a living organism is built. And it is built of macromolecules.

However, prior to even proceeding with the solution of this most important and absorbing problem it is necessary to have the innermost knowledge of the chemistry of living things, i.e., of how the "factory" producing them functions. Only then will it become clear what problems face macromolecular chemistry. Only then can successful attempts at prophecy be made concerning the creation of new materials.

* *

Is it possible to synthesize a living organism?

Only a few decades ago the mere posing of such a question was deemed sacrilegious. Experimental evidence of the fact that the life processes are essentially chemical processes confirms the basic idea of dialectical materialism that proclaims universal unity.

The evidence we refer to was obtained in recent years and it has brought about a revolution in the thoughts of men, including those who grudgingly agreed that living matter, in principle, consists of the same electrons and atoms of which iron beams and

stone columns are composed. That can well be understood. It is one thing to accept an abstract principle, the realization of which, you are sure, is practically impossible. It is quite another thing to begin to think seriously about the matter when you have learned the mechanism of the chemical synthesis of a living organism and you see that the principle works, be it even in the simplest case.

The history of science shows that if a phenomenon has been successfully attained on the smallest scale, if the truth of a natural law has been demonstrated in the simplest case, predictions by means of extrapolation are always justified. From a lamp with a carbon filament emitting a faint flickering light, there have sprung up lamps brighter than the Sun. A child's toy consisting of a wire frame rotating between two weak magnetic poles led to electrification all over the world. The path from a tiny laboratory screen made luminescent when exposed to radioactive particles to the freeing of the energy hidden in the depths of atoms turned out to be a rather short one.

Hence, there is no doubt that the first successful experiments in the synthesis of DNA (these letters will be decoded below) carried out in the 60's have opened the way to the chemical synthesis of living matter.

If only some twenty years ago, even among prominent biologists there were some who believed in the existence of "special laws" exclusively true for living matter and who raised an unsurmountable wall between animate and inanimate matter, at the present time it is hard to find any scientist who is not confident of ultimate success in the synthesis of living cells.

This confidence in the possibility of creating a "factory" for producing living matter, formerly only worthy of the attention of writers of science fiction,

is based first of all on adequate knowledge of the mechanism of transmission of hereditary characteristics and also of the process of protein synthesis, i.e., the synthesis of the molecules or "blocks" from which a living organism is built. The exciting story of this achievement was enacted before the eyes of one generation.

The classical period of development of genetics, when the gene was regarded as a formal, abstract and indivisible unit, came to an end only thirty years ago. The results of experiments in crossing different breeds of animals and species of plants, which agreed so well with Mendel's laws established in 1865, no longer allowed unbiased, knowledgeable researchers to question the existence of a bearer of genetic information. Naturally, a large number of biologists began to think deeply about just what genes were. Many of them understood that the ravine separating genetics from chemistry had to be spanned by a bridge.

At the end of the 30's it was demonstrated that a direct relationship existed between the colour of the eyes of mutant species of the fruit fly Drosophila and the biochemical synthesis of the pigment that imparts a given colour to their eyes. Since this biochemical synthesis was initiated and directed by a definite protein molecule (called an enzyme), the conclusion was drawn that mutation, i.e., variation in the gene, results in the loss of the ability to form the appropriate enzyme.

Each year the significance of this course of research became more evident. The fruit fly Drosophila turned out to be too complex for investigations and biochemists began to pursue scientific studies of the connection between gene structure and the synthesis of matter conducted by a living "factory" on microorganisms.

In the 40's the theory "one gene—one enzyme" was rather broadly accepted. The essence of this theory came to the following. Whatever the still mysterious genes might be, the responsibility of each of them for one or another hereditary characteristic (colour of eyes, shape of wings, etc.) is unambiguously associated with its chemical function in the synthesis of protein molecules.

Thus, it appears that genes are highly specialized: each of them produces one large molecule, a protein molecule, which in its turn has a definite task to perform, namely, to initiate the biochemical reaction and guide it in the required direction.

An elegant hypothesis, isn't it? It is precise and is based on the concept of the unity of nature. The nucleus of a cell contains genes; each of them is a machine for producing a protein molecule, and the protein molecule is the supervisor that controls the chemical reaction necessary for the growth of the organism and its normal vital functions. But how does all this take place? How does the gene produce the protein molecule? And what, after all, is a gene?

There were still many questions that demanded an answer. Sceptics claimed that even if the chemical interpretation of biological processes was theoretically possible it was, in any case, a matter of the remote future.

There were sound grounds for such an attitude. What is needed for interpreting biological phenomena? The answer is clear. It is necessary to describe in detail the atomic and molecular mechanism by which a protein molecule is produced by a gene. For this purpose it is necessary, in its turn, to know the structure of the gene and to obtain data on the structure of the protein molecule, i.e., to study in detail structures consisting of tens of thousands of atoms; to as-

certain how they are bound to one another, in what sequence they are arranged, what configuration is formed by the chain of atoms connected by valency bonds. But is it possible to solve such a complex problem? At the end of the 40's the way to its solution was only dimly perceivable. Only a few far-sighted people set out to seek the blue bird.

Little more than twenty years have passed since then. In this period of time a relatively small army of researchers, biophysicists and biochemists have accomplished a scientific feat which can be compared to Darwin's discovery of the theory of evolution. The structure of the gene has been ascertained; the atomic structure of several tens of protein molecules has been determined; the mechanism of the transmission of hereditary factors has been explained; it is now known how the genes produce protein molecules; mutation has been translated into the language of atoms; intervention in biochemical synthesis has been effected; and finally, a way has been outlined for synthesizing living matter. And all of this in a period of twenty years! If our knowledge in the field of molecular biology continues to increase at the same rate—and most probably that will be the case—the cultivation of living organisms in chemical flasks and the improvement of organisms by correcting flaws due to non-selective gene control of heredity of characteristics will be a reality at the beginning of the XXI century.

Many biologists believe that the romantic period of molecular genetics is over. The fundamental laws of this branch of science have been established and it now remains to perform a great deal of painstaking work. It is necessary to ascertain the mechanism of the numerous processes that take place in a living organism, to determine the structure of thousands of biological macromolecules.

The above term was generally accepted only at the beginning of the 50's, although it was first used considerably earlier.

J. D. Bernal and W. Astbury, pupils of W. H. Bragg and W. L. Bragg (father and son) who discovered X-ray defraction analysis (the principal method for studying the structure of matter), were probably the first investigators who in the 20's and 30's made an attempt to determine the distribution in space of atoms in the structures of nucleic acids and proteins. They came to the conclusion that this was the only way of solving the puzzle of how a living organism functions and claimed that the interpretation of biological facts on a molecular level was, in principle, possible. And they were not mistaken.

Let us skip a few decades and in telegraphic form inform our readers about the present state of the art. We should begin with the structure of protein molecules.

It has long been established that the protein molecule is composed of a chain consisting of 20 different "building blocks"—amino acids. We shall not name them although some of the names, for example, methionine and glutamine are familiar to those who seek relief from illness in drugstores. The amino acids are joined by identical rings (chemists call them peptide linkages). Hence, to ascertain the structure of a protein molecule means, first of all, to determine the sequence of amino acids. But this is not all. It is also necessary to know the configuration of the molecule.

Numerous laboratories are now engaged in this hard work. Apparently, biologists needed to know the structure of all the proteins. So that in some perceivable future there will appear on the bookshelves of libraries a thick book containing data on the sequence of amino acids in all protein molecules.

The importance of this data cannot be overestimated. One or two changes in the sequence of the amino acids is enough to cause radical changes in the life of an organism. A congenital disease or serious deformity can result from slight variation in the structure of a protein.

Exceedingly interesting is a comparison of the structure of one and the same protein in various organisms. To our amazement, for instance, there is only a slight difference in the sequence of amino acids in the haemoglobin molecules of man, the horse, the bull and the mosquito. Insignificant variation in the sequence of amino acids attended the evolution of living organisms from the lower to the higher forms. The course of evolution can be faithfully traced by studying the molecular structure of proteins of various animals.

So that extrapolation based on the course taken by science today allows us to assume that the shelves in the bookcases of libraries will contain many volumes rather than the one book *Protein Structure.*

The difficulties encountered in structural analysis have not prevented the rapid progress of molecular biology in defining the relationship between the structure of proteins and the mechanism by which the vital functions of living things are governed.

Attention should be drawn to altogether new trends in the organization of scientific research in this field.

Haemoglobin is an important protein; there is no need to prove this even to those who do not know that this molecule carries out the function of blood transfer of oxygen that is so essential to life. Anyone anxious about the health of his close relatives or friends knows how bad it is if the blood test shows a small percentage of haemoglobin in it.

Haemoglobin is, of course, an important protein but there are hardly any proteins in the organism that are

not important, i.e., which could be dispensed with. There are no "loafers" among the proteins. To acquire the knowledge of how each of them functions is a problem which sooner or later must be and will be solved. This will be accomplished by the generation of scientists who today are still attending schools or universities, as well as by those already in the ranks of the army of researchers.

Molecular biologists have not had time yet for investigating the majority of the proteins. But as concerns haemoglobin, a thorough study of it has already been launched. At the present time there are approximately 100-200 people in the world who are studying the relationship existing between the structure of haemoglobin and its properties. Haemoglobin is their profession.

Since no obstacles stand in the way of personal contacts between scientists of different countries conducting research into the structure and properties of haemoglobin—it is not an explosive and is not a material suitable for atomic bombs—those occupied with solving the same problem are irresistably drawn to one another. There is no need for them to look through many journals to find each other's articles. They often meet at symposiums and conferences, maintain a lively correspondence and in this way are constantly well informed about the latest events.

International cooperation is nowadays characteristic of work conducted in the fundamental (or as they are called in the West "pure") sciences.

There is no need for emphasizing how thoroughly the 100-200 persons know their subject. I recently attended a lecture on haemoglobin. The lecturer knew the sequence of amino-acid residues in the haemoglobin molecule by heart. He drew our attention to certain places in it—"Here is tryptophan No. 93, and here

where residue 48 adjoins residue 54 the main chain (backbone) of the molecule is curved". He spoke of the haemoglobin molecule like a geographer would who having lived about 10 years on a tiny island knew every inch of it—the location of every mound and the thickness of every tree trunk.

It is indubitable that all the secrets of haemoglobin will be disclosed in the next few years thanks to the united efforts of this international association of researchers.

It can be assumed that after studying the relationship between the structure, the configuration of all the proteins and their functions in an organism, science will proceed to prescribe means for correcting molecules that function improperly.

However, it is more likely that in a few decades scientific medicine will be devoted to curing the director of the cell, the DNA molecule itself, under the command of which the production of proteins is carried on. So that instead of "mending" a molecule of poor quality produced by a "factory", would it not be better to replace the director and stock of automatic machines?

The structure of the DNA molecule—deoxyribonucleic acid—was sooner guessed than found by experiment. The authors of this remarkable discovery, D. Watson and F. Crick, made good use of data from allied fields of science: chemistry, genetics, crystallography. Needless to say, they could not do without experiments. Just the same it can be said without any exaggeration that they invented the double helix and having done so they immediately saw how readily and simply this model explained all the known facts involved. Such an elegant hypothesis could not fail to be valid—and indeed it did not. A series of investigations following the work of D. Watson and F. Crick de-

monstrated the correctness of the model of the double helix.

The DNA molecule commands the living organism. It carries out two functions. First of all it serves as a matrix for reproducing another identical DNA molecule—the process that is the basis of cell division. Secondly, it implements protein synthesis. This it accomplishes in two stages. The DNA molecule produces the matrix of the RNA (ribonucleic acid) molecules which in their turn produce the units of which the various proteins are composed.

The DNA molecule is responsible for the transmission of hereditary characteristics. Does this mean that the gene is a DNA molecule? No, genes are only parts of the DNA molecule. But we shall speak of that later.

What is the main condition that must be satisfied by the molecule that is responsible for the transmission of hereditary information? The answer to this questions was, in essence, given as early as by E. Schrödinger, one of the first to discover quantum mechanics, in his little book *What is Life?* which had such a great influence on those who ten years later came to be known as molecular biologists. It was clear to E. Schrödinger that the molecule that governs the transmission of hereditary characteristics must be an aperiodic crystal. The combination of these two words sounds approximately like "a bitter sweet" since periodicity is an attribute of a crystal. By this E. Schrödinger wanted to emphasize the fact that a gene in some way or other (he had no idea in exactly what way) had to combine order and disorder.

Order is necessary because there is an enormous number of the same genes in various cells. But strict order is not consistent with the idea of a molecule in which hereditary information is stored. An orderly system can be described by tens or maybe hundreds

of characteristics, which only testifies to the poverty of such sources of information. It is impossible to send a telegram containing very much information with the aid of only dots or only dashes or regularly alternating dots and dashes.

Conversely a system in which the consecutive order of dots and dashes is irregular affords unlimited possibilities for the transmission of information.

When D. Watson and F. Crick began their research, it was already known that the DNA molecule consists of a long backbone chain and side chains (coils) of four types; these are the nucleotides: thymine, cytosine, adenine, guanine. The first two side chains (the smaller ones), although differing slightly from each other, are very much alike. The other two (the larger ones) likewise differ from each other slightly.

Not long before the two future Nobel Prize laureates began their research, chemists had begun to suspect that the sequence of the nucleotides in the DNA molecules of various individuals differed. Long chains in which nucleotides that are very much alike, yet not exactly the same, are arranged irregularly agree well with E. Schrödinger's idea of an aperiodic crystal.

The DNA molecule of the simplest bacterium is of an enormous length. The number of side chains in it is equal to 6 millions. It is not hard to estimate that a book written using six million words of a 4-letter alphabet will contain 3 thousand pages. So that both ends meet perfectly. Three thousand pages is quite enough to describe the structure of a bacterium in great detail.

D. Watson and F. Crick were faced with the task of imparting concrete features to the long aperiodic molecule and of presenting a model that would explain the two major functions of the DNA molecule—replication, i.e., the reproduction of copies of itself and the

production of highly specialized protein molecules (specific for each organism).

D. Watson and F. Crick showed that when two DNA molecules approach each other, there is only one convenient way for two identical molecules to coil together to form a whole. It is convenient for the small thymine side chain to approach the large adenine chain and for the small cytosine side chain to approach the guanine chain.

Nature proceeds in the same way as a locksmith. A lock can be opened only if all the projections on the key match the respective recesses in the lock. There is likewise only one way for the molecule to intertwine into a double helix; the small coils play the part of keyholes while the large coils that of the projections on keys. Any variation in one of the molecules being paired is sufficient to make intertwining impossible.

The "key-lock" principle adequately explains the division of cells. The strands of the double helix uncoil and each one picks up from the raw material at hand a second molecule identical with the parent.

This explanation is so natural that it was unanimously acknowledged even before any direct evidence was available; such evidence, however, was not long wanting.

The mechanism of protein synthesis is much more complex. The "unit" that transmits hereditary factors was found to be a sequence of approximately a thousand nucleotides which was named a cistron. Each cistron is responsible for the production of a polypeptide—a chain of amino acids joined by peptide linkages. The previous formula "one gene—one enzyme" was replaced by the rule "one cistron—one polypeptide".

Thus, it was found that the gene was not a molecule but only a part of one.

The director of protein synthesis is the DNA molecule. At any large industrial plant the director does not command production directly but does so through his assistants, for instance, the chief metallurgist, the head designer, etc. Generally, the director appoints his assistants himself. The DNA molecule behaves in the same way with the difference that it not only selects its assistants but even produces them. The immediate executors of the will of the director are the molecules of ribonucleic acids that act as messengers (mRNA). The mRNA molecule is an exact copy of a section of the DNA molecule of a length of one cistron.

Thus, the mRNA molecules are entrusted with the synthesis of proteins. And this is as it should be. Otherwise an undesirable crush would arise near the DNA molecule and entanglement in the flow of "raw material" necessary for the production of various polypeptides; synthesis would proceed at a slower rate and all kinds of mistakes would be likely to occur.

The DNA molecule produces a large number of mRNA molecules—in principle, as many as the number of gene-cistrons that it contains. The mRNA molecules set out to synthesize protein molecules in shops called ribosomes.

But it is necessary to deliver the raw material to these shops! This function is carried out by transfer molecules—ribonucleic acids of another kind, denoted as tRNA. There are as many transfer RNA as there are amino acids. Each tRNA carries along its amino acid. That is how an organism functions.

The correctness of this model has been proved by direct experiments. Of course, in this article it is impossible to give an idea of the whole complex of evidence on which this hypothesis is based. We have

simply outlined the mechanism of the work of a living cell in the broadest terms. In recent years the most subtle details of this process have been studied by biologists. The secrets of the synthesis of living matter are now in the possession of science.

* * *

Like any other knowledge, this poses the following questions: what for, for what purpose? Will it be conducive to greater happiness on Earth?

The answers to these questions are quite obvious. First of all, knowing the recipe, i.e., the ingredients and conditions (the "kitchen") for preparing living organisms, man would be able to intervene in the process if the cook made a bad job of it. Secondly, the very idea of the possibility of creating artificial creatures in accordance with a present plan is enough to make one's head dizzy. Both tasks will not be achieved for a long time yet and at present can be relegated to the realm of fantasy. However, even if they are fantastic, their achievement is quite realistic, i.e., not inconsistent with natural laws. Furthermore, what has to be learned to this end is sufficiently clear. The synthesis of proteins and nucleic acids is a scientific problem of the greatest importance.

It is still hard to predict how the ability to do this will be used for carrying out the two tasks in the programme of intervention in the process of producing living matter. There are grounds for believing that cells can often be "deceived" by introducing an artificial nucleic acid to modify the synthesis of one protein or another.

When studying the subtle effects of the work of a living cell it is of major importance to the biologist to simulate the separate stages of the processes occurring

in a living organism. For this purpose it is also necessary to learn how to synthesize protein molecules, RNA molecules and other biological macromolecules to a preset plan.

The most remote dream, apparently, is the synthesis of the "commander in chief" of this process—the DNA molecule. If this problem were solved, the whole process of production of living matter could be accomplished in a chemical flask.

The author of the above statement, however, will not allow his thoughts to be carried away as far as that. He would be very glad if his most immediate descendants witnessed the conversion of medicine into an exact science. And that will be possible only if biochemists and physicists learn how to determine the structure of the proteins and nucleic acids of each individual, to understand the mechanism of any disease and to master the technique of intervention in the vital activities of an organism, which consists in replacing "sick" molecules by healthy ones.

All these problems demand the exertion of gigantic efforts. Nevertheless, their solution is not beyond the power of modern science. The author of this article believes that any chemical research is justified if it contributes anything to the solution of biological problems. It seems to me that all other problems concerned with the synthesis of new molecules and new substances are minor ones compared with those posed by molecular biology.

Science, after all, has already done almost everything to give man a life of comfort. But the new society implies the collaboration of happy, healthy people. The annihilation of disease and the bringing up of harmonious individuals—these are problems that are not less important than the creation of new means of communication and transportation and new dwel-

lings. The solution of these problems is what science still owes to mankind.

That is why I think that the principal prediction in an article dedicated to the future of the science of matter can be stated as follows: the first to be developed will be all the branches of physical chemistry that in any degree contribute to our understanding of the nature of the life processes and pursue the object of mastering the means of intervening in the holy of holies—in the synthesis of living matter.

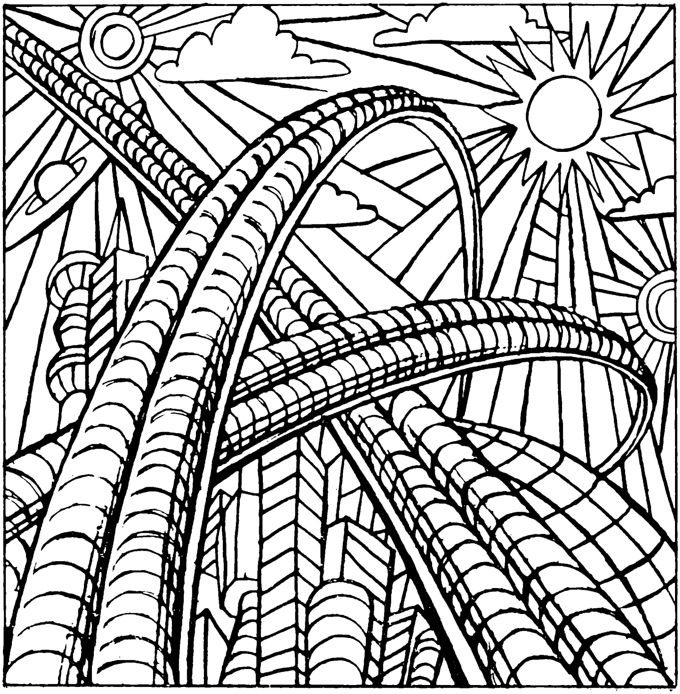
A STORY OF

TRANSPORT IN THE FUTURE

AS TOLD BY

V.S. MOLYARCHUK

DOCTOR OF SCIENCES



Transport, like any other industry, obeys the laws of economic and social development that apply to the whole of the national economy. Unlike other industries, however, it works basically by converting heat or electricity to mechanical energy, which is directly utilized to move goods and passengers, that is, to do work of haulage.

From this naturally stems the close functional relationship between what a transport worker has at his disposal in terms of power and how well he can do his job.

What a transport worker has at his disposal in terms of power we shall call the available per-head power and define it as the nominal or rated horsepower (hp) of vehicles per transport worker. Or we may define it as the quotient of the total horsepower of vehicles per total number of people running these vehicles.

Theoretically, the performance of land and water transport is related to the power available by a general equation of the form

$$P = AN_y \text{ tonnes-km/men-year}$$

The coefficient A takes care of many variables of transportation, such as the cargo-carrying capacity of vehicles, speed of traffic, servicing time, running time, and utilization of cargo-carrying capacity and rated horsepower. Analysis of practical data for all forms of transport over the past 20 years has shown that the coefficient A in this equation remains constant due to the cumulative effect of all variables, being 69,500 for rail, 97,750 for river, and 3,000 for road. Hence we may say that over the past twenty years the performance of rail, river and road transport has been directly proportional to the power available.

* * *

Study of changes in available per unit power in main-line transport, notably on railways, has shown that its growth has principally been due to increase in the rated power of traction units (say, locomotives), while the growth in the number of people employed in transport has been relatively insignificant. The rise in the average rated power of locomotives from 2,000 to 3,500 hp has raised the average available power from 11.5 to 20.4 hp/man, and performance from 800,000 to 1,400,000 tonnes-km per year per man. Transport performance has improved because bigger power plants enable locomotives to haul heavier trains, automobiles, river craft, sea-going vessels and airplanes to carry more cargo and more passengers and do that at a higher speed.

Power plants for transport uses must above all meet stringent requirements for weight and size because both are at a premium in any vehicle. Also, they must be economic in burning fuel because any increase in the fuel carried cuts down the payload and range of ships, aeroplanes, automobiles and locomotives.

In the latter half of this century, the steam piston engines used on land transport had reached the reasonable limits of size and weight and had become an obstacle to further progress. This is why the 1950's and 60's saw a sweeping change in the sources of power used.

Both in the Soviet Union and abroad, steam piston engines gave way to internal combustion engines using electric and hydraulic drives. As a result, the 70 to 90 kilograms of structure per hp in steam locomotives dropped to 45 to 60 kilograms in Diesel locomotives and 23 to 37 kilograms in electric locomotives. Or, taking the same weight per axle for which railways set

rigorous norms, the rated power of Diesel locomotives was raised 2.2 times and that of electric locomotives 2.7 times in comparison with the most advanced steam locomotive. Also, internal combustion engines burn only one-fourth to one-fifth of the fuel for the same work done, and this means a five- to ten-fold increase in the range of Diesel and electric locomotives.

The urgent need for bigger transport power plants gave strong impetus to changes. Between 1960 and 1970, the share of novel types of power plants in the Soviet Union increased from 26.2 to 92% for locomotives, from 66.9 to 85% on sea-going vessels, and from 70 to 94% on river craft.

The change was still more dramatic when aeroplanes switched from piston to turbo-jet engines. Above all, there was a sizeable cut-down in the weight-to-power ratio. For piston engines it was 0.55 kg/hp and for turbojet engines about 0.06 kg/hp. Now engines packing huge power could be built to propel aeroplanes carrying increased payloads at the speeds that piston engines could not give because of their heavy weight and of their propellers whose pull drastically reduces at 700 to 750 km/h.

In a very short span of time, the change-over from piston to turbo-jet engines increased the payload of Soviet aeroplanes three to four times, and their speed two to two and a half times.

These new types of traction and power plant have removed the limitations forced on progress by steam piston engines, and today nothing stands in the way of progress for the traditional forms of transport. In other words, goods in the nearest decades, up to the 21st century, will continue to be carried by the traditional forms of transport, mostly by rail.

Now that international relations are growing ever closer and international trade is continually expanding,

the merchant marine is surely in for a good share of expansion, too. River craft will not lose their importance, either, and we shall see further expansion in road and pipeline transportation. Passengers will rely increasingly more on airlines, buses, and private cars.

In every form of transport, progress and capabilities are above all decided by advances in power plants, because they control performance, economy, safety and mobility.

Advances in power plant design not only make transport systems more efficient, but also may expand or even change their fields of application in civil life and defence.

Over the past twenty years, electric and Diesel traction on the Soviet railways has increased the train weight 1.8 times and speed by two-thirds, which is a major advance in performance. As a result, the amount of carriage over the same period has increased fourfold. There have also been substantial improvements in working conditions, as no arduous and labour-consuming operations in the servicing of steam locomotives are any longer needed.

With automatic control systems, several electric or Diesel units can be operated from the same cab, and remote control provides a means for such an arrangement of locomotives in a train that traction force is distributed evenly and the brake system can operate efficiently. Owing to these new aspects of electric and Diesel traction, the weight of trains can be increased practically without bound and less stringent requirements may be laid on the unit power rating of locomotives; it may be raised to 4,000 to 6,000 hp per unit for Diesel locomotives, and to 10,000 to 14,000 hp for electric locomotives.

While supplying more power, locomotives will become more economical owing to the use of new control

systems based on semiconductor devices, return of electric energy to the contact-wire system, use of better insulation and other special-purpose materials.

It is likely that railways will widely use high-power gas turbines burning heavy oil fuel. Some railways outside the Soviet Union are already using gas turbines for high-speed trains.

In most cases, railways are so profiled that total traction power is only utilized on difficult stretches accounting for not more than 20% of the total length of a railroad. Therefore, it will pay to combine in the same locomotive a Diesel engine as the main traction prime mover and a gas turbine for use at starting, speed-up and on especially difficult stretches. A number of such locomotives have already been put in operation in the Federal Republic of Germany.

For all the advantages of novel types of tractive power, however, electric and Diesel locomotives which in the Soviet Union began to be built in 1920's and 1930's and went into mass use in 1960's will remain the basic elements of the Soviet railways for decades to come.

* * *

At present, Diesel engines are the predominant prime movers for ships. A marine Diesel engine is reliable in service, can be reversed at will so that the ship can be handled with no special reversal gear, and is fairly economical as it utilizes fuel at an efficiency of 40%. With a rotational speed of 90 to 125 rpm, it can transmit power directly to the propellers without the need for complicated and expensive reduction gear.

However, this Diesel engine suffers from major drawbacks. Firstly, it is heavy. Assuming a weight-to-power ratio of 35 to 40 kg per hp, a present-day Diesel engine rated at 20,000 hp will "tip the scales" at 700

to 800 tonnes. Secondly, it is bulky, measuring up to 25 m in length and standing about 12 m high. A very large room is needed to house such an engine. Thirdly, the engine casing and all structural members of the engine-room must be extremely robust to withstand the impact of the rotating crankshaft, reciprocating pistons, and connecting rods, all of them developing large inertia forces.

This is why we have every reason to believe that although marine Diesel engines will keep gaining in power, they will never be built in units greater than 50,000 to 60,000 hp, even if medium-rpm designs are to be used.

Of late, quite a number of ships have been built, propelled by steam and gas turbines. A marine gas turbine, which is essentially a converted aircraft gas turbine, has a weight which is one-fifteenth of that of an equally rated Diesel engine. Although gas turbines are less economical in fuel consumption than internal combustion engines (their heat efficiency does not rise higher than 20 to 23% as against 40 to 45% in the case of internal combustion engines), they have a number of advantages which make them competitive enough; notably they are cheaper to operate and can be automated to a greater extent than Diesel engines. A gas turbine is simple to service and repair, and more reliable in operation because it uses no elaborate mechanical control systems, and can be started instantaneously.

As compared with other types of power plant, converted aircraft gas turbines have a shorter service life. Yet, they are probably the only type of prime mover for high-speed vessels utilizing novel principles of propulsion. In the Soviet Navy, they are used to augment propulsive power.

In discharging their duty, Navy vessels have to stay at sea for a long time. Mostly, they cruise at moderate power and moderate speed. But they must be able to build up both power and speed for short spans of time, if and when necessary. In the former case, the efficiency of the propulsion unit is important; in the latter it is not. This is why Navy vessels often use a combination of some economical power plant (such as Diesels or steam turbines) for sustained duty, and high-power gas turbines for short-time duty.

The use of this combination has also been dictated by the resistance into which sea-going vessels run as they are moving through the water. While the resistance to the motion of land vehicles increases as the square of speed, for sea vessels the increase is proportional to the cube of speed because the ships produce waves, and these add to overall resistance. As a ship picks up speed, the power plant has to deliver more power. For example, a destroyer needs 15,000 hp to move at 25 knots, 30,000 hp at 31 knots, and 45,000 hp at 35 knots. This is why a destroyer under construction in Great Britain will use a combination of a 15,000-hp steam-turbine plant and a 30,000-hp aircraft gas turbine for augmentation.

In the United States, the Coast Guard uses ships propelled by 600-hp Diesel engines in combination with 14,000-hp gas turbines.

It may well so happen that this combination will see service in the merchant navy on displacing, skimming and hydrofoil craft carrying perishable or especially valuable cargo.

Some displacing ships use heavier turbines showing improved economy and longer service life. One such ship was built in the United States in the 1960's; it has two gas turbines each rated at 20,000 hp and can move at up to 25 knots. A similar ship, the *Paris*

Commune, has been in service in the Soviet Union for a number of years already. At the time of writing, seven similar ships were under construction in other countries.

The gas-turbine vessels built in the late 1970's will markedly differ from those in service now, especially in terms of power plant economy and reliability. Calculations show that the use of heat-recovery circuits can raise the efficiency of marine gas-turbine units to 30-32% or even higher.

Since gas turbines are far smaller and lighter than Diesel units and also because gas turbines can be built up to 100,000 hp per unit, it is a safe guess that they will figure prominently as power plants for high-speed and special-purpose sea-going and river vessels of the future.

The development of nuclear power plant has perhaps been the most dramatic achievement for the Navy. The new prime mover has greatly changed the role and significance of some of the Navy's services, notably submarines. Existing nuclear submarines can stay at sea for months on end; they have a high speed, are extremely difficult to hit, and can launch nuclear-warhead missiles while submerged.

These qualities and capabilities which can be achieved by no other means justify the huge sums of money spent on the construction and operation of nuclear power plants and nuclear vessels.

The operation of the nuclear icebreaker *Lenin* (built in the Soviet Union in 1959) and of the passenger-cargo NS *Savannah* (built in the United States in 1962) and also the construction of the ore-carrying NS *Otto Hahn* (Federal Republic of Germany) and *Mitsu* (Japan) have shown that the use of nuclear power on transport ships is more in the nature of an experiment than commercial practice.

The nuclear power plant on the NS *Savannah* accounted for 60% of the vessel's total cost, as against 4 or 5% on conventional ships. The cost of the reactor plant installed on the NS *Otto Hahn* was 27.5 million Marks as against about 1.9 million the boiler plant of the conventional type and equal power would cost.

The reactor plant on the NS *Savannah* weighed 2,500 tons, which is 8 to 10 times the weight of steam boilers of equal power. The mechanisms installed in the machine-room were 10 to 30% heavier than conventional mechanisms.

In our estimate of the early nuclear vessels and nuclear propulsion units we should remember that they were experimental. We must not overlook the promise of improved economy and efficiency held out by further advances in the design and performance of reactors and propulsion units, and the inevitable cut-down in cost as more experience is gained in building and using the new machines which utilize nuclear power.

The high cost of a nuclear vessel and the higher wages for its crew will be more than paid off by the reduction in the overall weight and space of the power plant and fuel carried, by the cut-down in operating and maintenance costs, and better returns from operation of nuclear ships at higher speeds.

This is why, despite what may look negative practical results, many countries are continuing large-scale research and development work on improved designs of nuclear prime movers for ships and the ships themselves.

In 1958-1963, Japan carried out research and worked out plans for a nuclear tanker of 45,000 tons deadweight (total weight a vessel carries when immersed to her authorized load draft, including cargo, mail, fuel, water, stores, crew, passenger, baggage and per-

sonal effects), a passenger vessel, and an oceanographic research vessel. Norway and Sweden together designed a 67,000-ton ore-carrier; a tanker to be propelled by nuclear prime movers was designed in Netherlands. Similar work was done in Denmark. In 1958-59, the United States designed nuclear submarine tankers with a deadweight of 41,500 and 21,200 tons. In 1963, the United States carried out feasibility studies under a contract from Canada for nuclear submarine tankers to carry oil in the Canadian Arctic waters. Calculations showed that a nuclear submarine tanker would be only 30% more expensive to build than conventional surface tankers.

Current work on nuclear power plant has as its goal to improve plant design, above all by combining the reactor core, steam-rising and steam-separating circuits, circulating pumps and some of the auxiliaries used in the steam circuit in a single block. This would cut down the cost and improve the reliability of the machinery. For the same purpose, attempts have been made to bring down the water pressure in the steam circuit. In some designs, it has been proposed to replace water by, say, superheated steam or air.

There has been a marked improvement in the power-to weight ratio and operating variables of power plant. This ratio, including biological shield, was 80 kg/hp for the nuclear icebreaker *Lenin*, 120 kg/hp for the NS *Savannah*, and over 90 kg/hp for the NS *Otto Hahn*. For the nuclear ships currently under development, the figure is as low as 29 and 13.9 kg/hp. It has also been proposed to bring down the coolant pressure in the primary circuit from 123-180 atm to 45.7 atm, and to raise that in the secondary circuit from 28-35 atm to 46-62 atm, and the temperature from 240-310° C to 460-510° C, so that use can be made of highly efficient steam turbines.

The many technical and economic studies carried out in different countries have shown that, owing to advances in nuclear power design, nuclear ships can already now, at least in principle, compete successfully with conventional vessels in terms of economics.

According to US sources, nuclear ships carrying 7,100 tons of cargo and powered by 630A and CNSG reactors can move at 30 knots as against 21 knots attainable with conventional propulsion units occupying the same space (including bunker fuel). This gain in speed makes nuclear ships practically as economical as conventional ones for service in the North Atlantic, and in the Pacific the gain would be more sizeable on the longer runs.

According to UK sources, nuclear power plant may be attractive on passenger lines, large tankers and refrigerating vessels.

We may say with confidence that nuclear power plants rated at 30,000 to 100,000 hp and more will find wide use on large and high-speed vessels both in the near and the more remote future.

The ever-growing power of prime movers for ships has been accompanied by improvements in propulsion means. Apart from improvements in screw propellers, there has also been a good deal of work on novel types of propulsion.

In the 1960s, screw propeller designers turned increasingly more often to the idea of controllable pitch. Controllable-pitch propellers can be adjusted so as to secure the best possible efficiency. Also, the controllable pitch makes it possible to reverse the screw driven by a gas turbine. Of late, an increasing use has been made of supercavitating screw propellers.

There are good prospects for water-jet propulsion now that hydrofoil and air-cushion craft are gaining ever more ground. Basically, water-jet propulsion re-

duces to the following. Outboard water is drawn in by powerful pumps and discharged astern, above the water surface. As a result, the vessel is propelled forward by reaction force. The amount of water handled by the pumps is smaller than that scooped by a screw propeller, but the velocity at which the water jet is discharged is higher. The efficiency of water-jet propulsion units at speeds above 50 knots may be as high as 50 to 55%.

Water-jet vessels are lighter in weight, simpler to build and service, and can operate safely in shallow waters.

At speeds above 100 knots, any submerged propellers are of low efficiency. It appears, therefore, that for high-speed ships it might be advantageous to use large-diameter air propellers with an efficiency of 80 to 85%. In the circumstances, water-jet propulsion would be less attractive.

Limitations on the size and weight of sea-going vessels are less stringent than those on other craft. This is why the navy and the merchant marine can use advanced power plants such as nuclear and MHD-generators which have high fuel efficiency.

* * *

Advances in engine design dictated by the country's economic and social progress will inevitably affect other forms of transport as well. We shall therefore turn now to road transport, particularly automobile engines.

Because it is extremely versatile, road transport has been expanding at a very high rate. The first car appeared in 1885, and the world had 6,200 units by January 1, 1900. As of January 1, 1972 their number exceeded a quarter of a billion. To believe some fore-

casters, there will be 500,000,000 to 750,000,000 cars at the turn of the century.

In Russia, the automotive industry was practically built under the early five-year plans. As of January 1, 1931, the Soviet Union had as few as 28,500 automobiles against 35,800,000 the world over. After automobile manufacture had been put on a large-scale basis at the Gorky, Moscow and other motors works, a veritable automotive explosion occurred in the Soviet Union. Between 1935 and 1970, the share of automobiles in the total traffic flow had increased from 3.5 to 220.8 billion ton-kilometres.

However, automobiles in the Soviet Union have not yet become as important as they are in economically developed capitalist countries. They account for as little as 6 or 7% of the total freight turnover, which is only one-quarter of what they do in some capitalist countries. Yet road transport is important, indeed. Without it, there would be no regular cooperation between undertakings on the basis of specialization, which is the most promising way of development in industrial production, nor could residential and industrial buildings be erected from factory-fabricated large-size blocks and panels, nor could large-scale farming be managed, and open-cut mining would be inconceivable. Last but not least, road transport is often at the start and end of a production process or acts as an intermediate link between main-line carriers and their clientele.

This is why the share of road transport in the country's transport system is and will be growing.

Since the first automobile made its appearance, the automotive engine has greatly improved in design, power and styling.

In the Soviet Union, as in the rest of the world, the principal type of automotive engine is the carburet-

tor Otto-cycle (spark-ignition) engine. About 10% of heavy-weight trucks use Diesel-type or compression-ignition engines. Very large trucks are beginning to use gas turbines. It is reasonable to think that road transport of the future will widely use gas turbines with up to 1000-1,200 hp, because such vehicles can find many applications. The internal-combustion engine will, however, remain the basic type.

The carburettor engine has many advantages over the Diesel engine: it is cheaper to make and repair, it has a smaller weight for the same power. On the other hand, the Diesel engine operates by a better and more economical thermodynamic cycle and its exhaust is cleaner. The average efficiency of carburettor engines in the Soviet Union is 24.3%, and that of Diesel engines, 33.6%. The latter burn 28% less fuel; under favourable conditions the saving in fuel may be as high as 30% or even more. This saving of 30% for automobiles used on a mass scale is a very important factor, as it is related to the most scarce grades of fuel.

It has been stressed more than once that the large-scale use of automobiles entails grave social consequences, such as air pollution in big cities. According to various sources, one automobile powered by a carburettor engine discharges 800 to 900 kilograms of harmful products a year. In a report to the US Congress, the amount of harmful products discharged by automotive exhaust in the year 1966 was put at more than 80 million tons, including 60 million tons of carbon monoxide, about 7 million tons of hydrocarbons, and 5 million tons of nitrogen oxides. The polluted air is laden with aggressive acids which attack metal structures. The loss due to this factor was estimated at 11 billion dollars. The harm done to the health of city dwellers by the polluted air is difficult to express in terms of money. Smog in Los Angeles, Tokio and

New York has become a veritable scourge for their inhabitants. Noise from the cars swarming in the streets also adds to their discomfort.

Thus, apart from satisfying the needs of present-day society by carrying passengers and freight, automobiles when used on a mass scale pose grave social problems and constitute a heavy drain on the ever-shrinking reserves of energy resources.

One way out is to install Diesel engines on heavy and medium trucks and buses. Some headway in this direction has already been made in many countries. The Federal Republic of Germany has arleady Dieseled 52% of its trucks, 90% of its buses, and 100% of its towing trucks; Great Britain has done so with 38% of its trucks and 90% of its buses; in France, 24% of the trucks and 71% of the buses have switched to Diesel engines.

If the Soviet Union had as many Deisel-engined automobiles as the FRG has, the consumption of fuel would be cut down by 7.5 to 8 million tonnes at the present-day scale of traffic, and the air in the cities would be much cleaner.

Attempts have been made to apply fuel injection to carburettor engines as a way of enhancing the economy of the Otto cycle; however, the saving has been only one-third of that given by Diesel engines.

The Wankel rotary engine may well provide a means for reducing the noise produced by automobiles and to cut down their weight. Japan has already been making cars with the Wankel engine, and similar cars will be manufactured in the FRG and the USA.

Today, however, the Wankel engine is still less economical and its thermodynamic cycle is less efficient than those of the conventional engines, and its exhaust carries a good deal of toxic gases.

The best way to resolve the air-pollution and economic problems posed by the mass use of automobiles is to switch to electric vehicles.

Historically, the electric car is the same age as the automobile. Because of complexities in its design, however, for the 250 million automobiles in use all over the world today, there are as few as 40 or 45 thousand electric vehicles. Of this number, about 29,000 are in Great Britain, about 3,000 in the FRG, and the remainder in the United States, Italy, France, Japan and some other countries.

Nearly all of the present-day electric vehicles are freight-carriers with a capacity of 800 to 1,000 kg. They are used to deliver merchandise, foodstuffs, etc. According to data for 1969, there were only about 100 electric cars and several experimental electric buses in the world.

The main roadblock to the wider use of electric vehicles is the lack of adequate storage batteries. Because of the batteries, the electric car today is still more expensive than the automobile; its speed is low, and its batteries need frequent recharging. Its electrical equipment accounts for half the total cost, and 90% of this goes into the storage batteries.

The storage batteries available today are the acid-lead, iron-nickel and nickel-cadmium varieties, with a capacity of 200 to 500 ampere-hours, a power-to-weight ratio of 33 to 36 watts per kilogram (up to 100 W/kg in the short-time duty), and a service life of 1,600-1,800 cycles.

A viable battery-powered electric vehicle should look as shown in the table.

As is seen, existing storage batteries are not good enough for traction service. They have just enough

Type	Range, km	Speed, km/h	Power/weight ratio, W/kg	Energy/weight ratio, Wh/kg
Compact electric car	80	65	145	55
Medium-class electric car	160	95	228	122
Large-class electric car	320	110	244	270
Electric truck	160	65	88	73
Electric bus	200	50	78	93

"juice" to last 30 to 40 km of travel at a bare 25 or 26 km/h.

Apart from the inconveniences involved in their servicing, such electric vehicles would congest the streets which are almost suffocated by traffic already. This is why they have so far met with limited acceptance, although their batteries would make them quite attractive in some applications. According to the press, where they are used, electric vehicles are carrying freight at the same or even lower cost than the conventional automobiles.

The growing urgency of air pollution and traffic noise has been a big shot in the arm for the development of electric vehicles capable of replacing automobiles in every respect. Much effort is being put in research and development work on better batteries and cars. Between 1965 and 1971, several designs of electric vehicles appeared, with a range of 64 to 80 km and a speed of 40 to 50 km/h. At the time of writing, the West-German firm of Messerschmitt-Belkow-Blom was working on a one-ton electric truck. Work on electric trucks and, especially, cars is under way in the United States, the FRG, Great Britain, Japan, Italy,

the Netherlands, and France. Experimental electric vehicles have been developed in the Soviet Union, Czechoslovakia and Bulgaria.

Apart from storage batteries, designers have also tried fuel cells as sources of electricity for electric vehicles. In contrast to storage batteries where chemical energy is converted to electricity with the aid of plates (electrodes), a fuel cell converts chemical energy into electricity directly. Unfortunately, fuel cells are still very expensive, and their output power per unit weight is one-fiftieth of that of internal-combustion engines, although the figure is comparable with the performance of storage batteries.

As generators of electricity, fuel cells have a fairly high efficiency, theoretically close to 100%, and practically ranging between 40 and 80%.

As is seen from the table below, an electric vehicle comparable with the conventional automobile in performance is still an unresolved problem.

Power source	Energy-to-weight ratio, Wh/kg
Lead-acid storage battery	20
Nickel-cadmium storage battery	55
Zinc-silver storage battery	132
Zinc-air storage battery	176
Sodium-sulphur storage battery	330
Lithium-chlorine storage battery	440
Gasoline internal-combustion engine	2,200

If we recall that only the first two types of storage battery can actually be used because the remaining types are very expensive to make, it is obvious that

the problem is formidable, indeed. Yet, it will be resolved because of its urgency—this is a social responsibility of engine designers, too.

An end to air pollution in big cities must, however, be put already now, and some firms have turned to ways and means for cleaning up the exhaust and to hybrid vehicles using both storage batteries and light-duty engines.

This combination may operate either in tandem where all power of the engine goes to drive the generator which energizes the traction motor and to trickle-charge the battery, or in parallel where only part of engine power is expended to drive the generator which trickle-charges the battery, and the greater proportion is utilized to spin the drive wheels. The energy delivered by the generator and engine is split between these users by an automatic control unit.

In some hybrid designs, the weight of the electric plant is one-eighth to one-tenth of that in battery-powered electric vehicles, and the vehicle has extreme flexibility in energy disposal and offers capabilities comparable with the performance of the conventional automobile.

In the United States, such a hybrid vehicle has been developed by the General Motors. Its engine is an external-combustion Sterling piston-engine which produces an almost clean exhaust. Similar engines are used by some electric vehicles developed in Japan and the Canadian electric vehicle developed at Toronto University.

In their estimates of prospects for the large-scale use of electric vehicles, experts believe that quantity production of hybrid cars may be expected in 1975-1977, and that of vehicles using fuel cells beyond the year 2000. In our opinion, too, unless some breakthrough occurs in the use of fuel cells, hybrid cars will

be the first to be added to the fleet of automobiles in the Soviet Union, and the fuel-cell electric vehicle will appear in the next century.

* * *

The types of power plant we have examined are fairly universal. They, or their modifications, may well be used on any land vehicles.

In aviation, a real breakthrough occurred in the 1930s-1940s, with the advent of the jet engine. The very logic of its operating cycle makes the jet engine admirably suited for high-speed aircraft. While the economics of the Diesel engine, the gas turbine or the nuclear power plant depends solely on the efficiency of their thermodynamic cycles, the transport efficiency is decided by the speed of the vehicle and expressed as

$$\eta_p = 2V/(U + V)$$

where η_p is the propulsive efficiency, U is the velocity of the jet, and V is the speed of the vehicle.

For example, a jet engine with a jet velocity of 2,100 km/h propelling an aircraft at 970 km/h would have a propulsive efficiency of 63%. If the same jet engine were installed on a railway vehicle or water craft travelling at 200 km/h, the propulsive efficiency would be as low as 17.4%.

This is why the jet engine is suited solely for air transport. It can show maximum propulsive efficiency only if the velocity of the jet issuing from the engine nozzle is at least half the speed of the aircraft. This relationship is, and will be, governing the development work on power plants for aircraft. We shall see novel types of gas-turbine, jet-turbine, turbo-fan and afterburning turbo-jet engines for aircraft.

Progress in engine construction will lead to compressors and turbines utilizing high pressure differentials and air-cooled turbine blades which can be driven by a gas raised to 1,000 1,100°C.

It appears that the basic type of jet engine will be the ducted-fan turbine engine with a high flow rate of air in the outer circuit and a compression ratio of as high as 25 : 1. This is nearly twice as great as the compression ratio used in the present-day jet engines and higher than in Diesel engines.

The high-pressure, high-temperature gas spinning the blades will raise the propulsive and overall efficiency of the engine to 35%. On aircraft, such engines will raise the load-carrying capacity to 100-120 tons at a speed of 920-950 km/h.

Jet engines for supersonic aircraft will also be improved. The power plant of a supersonic aircraft has an air collector, an engine proper, and a variable-area nozzle. The engine also has a reheat unit or afterburner to raise the velocity with which the jet issues from the nozzle.

It may well happen that novel types of engine will be installed on supersonic aircraft, notably those using a heater unit for the air drawn in by the fan. This can improve thrust by 30 to 40%.

Such high-performance engines can develop a huge thrust. For example, for the TU-144 flying at 2,500 km/h it is 17,400 kg per unit, and the total thrust of its four engines is 69,600 kg, which is equivalent to 172,000 hp. The total thrust developed by the engines of the *Concord* designed for flights at Mach 2.2, or 2,260 km/h, is 72,000 kg, and the *Boing-2707* projected to fly at 2,900 km/h is to carry four jet engines with a total thrust of 114,000 kg, which is equivalent to 450,000 hp, necessary to climb at subsonic speed.

Work is under way on power plant for vertical takeoff and landing (VTOL) aircraft. Vertols are expected to replace helicopters which are too expensive to build and operate on cross-country routes.

Vertical take-off needs a thrust somewhat greater than the weight of the aircraft. In contrast, the thrust needed for cruise flight is 6 to 10% of the weight. This relationship suggests the use of two types of engine for vertols, one for takeoffs and the other for cruise flying, although other schemes may be used as well. The takeoff engine must be very light in weight and compact in size, with a weight-to-thrust ratio of 20 to 30 kg and may have a short overhaul period. An engine with an overhaul period of 500 hours would last 5,000 flights, which is equivalent to the overhaul period of present-day cruise engines.

A fairly great number of experimental VTOL aircraft have been designed to date, but for military uses only. Therefore, these aircraft will hardly see civil service before the year 2000.

* * *

There is much room for improvements in high-performance power plants such as Diesel engines, steam and gas turbines and nuclear steam power plant.

Further technical progress in powerplant design may lead to still better hybrid schemes, such as a combination of an internal-combustion engine and a gas turbine. A gas turbine may be teamed up with a steam generator. Or, still better, a gas turbine may be ganged up with a nuclear reactor to give an unlimited range to the vehicle equipped with it.

At the turn of the century or in the early years of the next, we may well see the use of electrochemical power sources on self-contained vehicles, which will not practically pollute the air or produce noise.

Because they set operational imits for vehicles, power plants determine the quantitative interaction between transport and the national economy. Above all, they govern the scale of haulage and the speed of traffic. As to the qualitative aspect of this interaction, such as protection against damage to the goods carried, cost of carriage and handling, it is determined not by power plants, but by the availability of vehicles meeting appropriate requirements as regards design and performance.

Therefore, another direction in the development of transport is to adapt vehicles to the pattern and properties of freight carried and to make cargo-handling completely mechanized and automated. While work on prime movers which started on a fairly large scale in the middle of the 20th century is already bearing fruit, that on vehicles proper has barely been commenced. The effort to improve vehicle design and capacity will undoubtedly cut down the cost of vehicle manufacture and the cost of haulage.

On railways, the past twenty years have seen an increase of 27% in load-carrying capacity of the equivalent car owing to the change-over to a greater number of axles started back in the 1930s, when the Soviet railways switched from two-axle to four-axle cars with a load carrying capacity of 50 to 62 tons. At present, eight-axle cars with a capacity of up to 125 tons and eight-axle tank cars with a capacity of 120 tons are being manufactured.

It is planned to make railway cars wider (3.75 m instead of 3.4 m). As a result, their capacity will be nearly doubled in the next 15 to 20 years.

In the USSR, the average load-carrying capacity of automobiles increased by 20 per cent between 1960 and 1970. At present, the trucks in use are predominantly with a capacity of 2.5 to 4 tons. On the other

hand, some 75% of the freight they are carrying is bulk cargo which can be handled best by trucks with a capacity of five to eight tons, of which they are only as few as 7%. This modest share of large trucks in the total fleet in the Soviet Union has been an outcome of the drive for a road transport based on a limited number of mass-produced basic models.

Now that, in addition to the Likhachev Motor Works in Moscow and the Gorky Motor Works in the city of Gorky, automobiles are coming from Minsk, Kremenchug and elsewhere and construction will soon be completed at the Kama Motor Works specifically designed to make eight-ton six-wheel trucks, the pattern of road transport can be tailored to the nature and lot-size of the freight carried.

Before long, a much greater number of heavy trucks and tractor-trailer trains will be seen on the Soviet motor roads. There will be a greater number of six-wheel cross-country trucks which cause much less wear and tear to the road pavement. This will be a major qualitative change in the road transport in the Soviet Union.

The pattern of road transport in the USSR can also be improved through a wider use of small trucks in the 0.8-2.0-ton class. In the Soviet Union, such trucks account for as little as 5 or 6% of the total, while their share is more impressive in many foreign countries. They account for 60% in the FRG, 66% in the United States, 68% in Italy, and 73% in France. It should be added, though, that the predominance of these trucks has mainly stemmed from their use by small farms and small businesses, which are non-existent in the USSR. Yet, small trucks may well be used by trading organizations, public services, post offices and other fields, where instead of professional drivers the trucks can be driven by forwarders, post-

men and the like. According to the Institute of Complex Transport Problems under the USSR State Planning Committee and the Road Transport Research Institute, the country's well-balanced truck fleet should preferably include 24% of trucks up to 2-ton capacity, 45% between 2- and 5-ton capacity, 14% up to 8-ton capacity, and 17% over 8-ton capacity. This well-balanced truck fleet would have carried the freight planned for 1975 at a cost 2,800 million roubles lower, and would have needed 1,950,000 drivers fewer.

Of late, cargo-carrying capacity has especially been increasing in the merchant marine, notably that of bulk carriers and tankers. Between 1960 and 1973, the average deadweight of bulk carriers the world over doubled from 18,500 to 37,000 tons, and nearly doubled for tankers. Back in 1960 the *Universe Leader*, with a deadweight of 104,000 tons, was hailed as a supertanker, but it was dwarfed by a tanker with a deadweight of 472,000 tons launched in 1972 in Japan, and plans are afoot to build tankers with a deadweight of a million tons.

The average deadweight of the oil-ore carriers ordered at the end of 1972 was about 150,000 tons. Some ten years ago, a timber-carrier with a deadweight of 5,000-6,000 tons was a big vessel; today, many of the timber-carriers under construction have a deadweight of 20,000 tons and more.

It may be expected, therefore, that towards the turn of the century the Soviet fleet will include bulk carriers with a deadweight of 150,000-200,000 tons, tankers with a deadweight of 300,000 tons, and container ships with a deadweight of 30,000-35,000 tons.

A similar trend is expected to take place in the Soviet airlines. In addition to the modernized subsonic 76-seat TU-134s, 158-seat TU-154s and 168-seat IL-62s, there will be new types of airliners seating as

many as 350 passengers apiece and aerobuses with a seating capacity of 450 to 500.

Carriers are expected to deliver goods not only in time, but also intact. Yet, a sizeable proportion of the freight is damaged because of inadequacy of railway cars and trucks to handle some classes of goods.

Tests have shown that a general-purpose railway car loses about 1.6 tons or 2.6% of the coal it carries, while the loss of ferrous and nonferrous ores is as high as 7%. About 3 million tons of chemicals are lost in transit every year, some 18 million square metres of glass, 2,000 million brick and up to 1 million refractories are broken on their way to users. Loss in transit amounts to 1-1.5% for cereals and 3-5% for potatoes carried in general-purpose trucks, and up to 5% for concrete delivered in dump-trucks.

This is why it is vitally important to design and build railway cars and trucks adapted to carry a specific kind of freight or merchandize and capable of utilizing the advantages of mechanized and automated handling facilities.

This form of specialization is wide-spread in advanced capitalist countries. Special-purpose railway cars account for 29% of the total in the United States, 27.7% in the FRG, and 21.9% in France. Specialized trucks, including pickups, number 84% in the United States, 89% in the FRG, and 77.5% in Great Britain. While in 1963 the special-purpose ships ordered for construction made up 40% of the total number of cargo carriers, in 1970 their share rose to 75%.

The same trend is noted in the Soviet Union. Instead of the general-purpose types predominant today, the fleets of railway cars, trucks and ships of tomorrow will be composed of a great variety of specialized types, each adapted to a particular merchandize and to particular cargo-handling facilities.

In the Soviet Union some 8 million people with a payroll of 14,000 million roubles a year are engaged in cargo-handling operations. Quite apart from the fact that their wages are a heavy burden on the nation's income, theirs is mainly arduous manual labour. Obviously, integrated mechanization and automation of cargo-handling operations in transport is an urgent social problem.

On the practical side, work is under way to improve the design of open cars, one of the basic types on the Soviet railways, so that they can be unloaded by tripping on a rotary car-tipper, without disengaging the cars from the train. This will be a logical extension of the work already done to mechanize the loading of these cars which carry the greater proportion of bulk cargo.

Cement will be carried in covered hopper cars and tanks fitted with air chutes for unloading. Mineral fertilizers will be transported in similar covered hopper cars fitted with loading and unloading facilities to fully mechanize these operations. Special-purpose cars will be used for cereals and raw sugar; special-purpose tanks will be developed for chemicals.

Big impetus will be given to refrigerated cars equipped with machines to maintain a temperature of —18 to —22° in summer and heat the cars in winter (should the goods carried need warmth).

A great number of two-deck flatcars will be put in operation for the transportation of automobiles; such a flatcar can carry 17 instead of three automobiles and has an added advantage of mechanized car loading, lashing-down and unloading.

Conventional general-purpose trucks and dump-trucks will give way to special-purpose types. For example, there will be special-purpose concrete-delivery trucks; there will be covered trucks for grain

to protect the contents not only against exposure to the weather, but also with coolers to keep down the temperature of the grain and devices to prevent friction in transit. Perishable foodstuffs will be transported in vans lagged and lined with highly efficient thermal insulation, or in refrigerated trucks using liquid nitrogen as coolant.

Truck bodies and wheel base will be proportioned to suit the bulk weight of the goods carried. Features and optionals will be incorporated to adapt the vehicles to various climates, especially the Arctic region.

Wider use will also be made of special-purpose seagoing ships and river craft. In addition to tankers adapted to carry liquids, loose and bulk cargo, special-purpose ore and timber carriers and dry-cargo vessels with facilities for mechanized cargo handling, there will be vessels specifically designed to carry a narrow class of merchandize. For example, ships will be built to carry only wine, or only cement, or only chemical fertilizers, or only vehicles, etc.

Special emphasis will be placed on the development of cargo vessels for service in the arduous conditions of the Arctic ocean.

A major contribution to cutting down the labour involved in transportation and cargo handling will come from the containerization system. With time, this system based on the use of standardized transport and handling facilities will be adopted by all countries of the world, especially for the carriage of most valuable and expensive unit cargo.

As the name implies, unit cargo is stowed in suitably designed containers which are stored at and handled by suitably designed facilities, transported by suitably designed vehicles, and the contents are unloaded only once—at the final destination by sui-

table mechanical means, without the need for loading and unloading the cargo piecewise anywhere else.

Any unit cargo needs packing. As a rule, packing is labour and time consuming. Because of this, unit cargo accounting for 10% of the total freight traffic takes up as much as 80% of all labour involved in cargo handling.

Containerization saves the materials and money that would otherwise go into the manufacture of crates, cases, and boxes. However, the vehicles must be of a special design permitting ease of handling and lashing-down, and their dimensions should be proportioned to fit exactly the size and weight of the containers or their multiples.

In the future, the share of container carriers will increase. On railways, these will be special-purpose flatcars of appropriate dimensions; on roads, these will be trucks or tractor-trailer trains adapted to carry containers; on sea and rivers, these will be special-purpose vessels with holds divided into compartments, fitted with facilities to lash down the containers automatically, and with cranes of an appropriate lifting capacity.

There will also be lighter-carriers, a variety of container carriers, also doubling as tankers for liquids, notably oil products. Lighter-carriers may be of one of two types. One is the docking type which will be able to take in from 20 to 100 lighters (barges) each with a capacity from several hundred to a thousand tons, and deliver them to destination where the requisite number of lighters will be left and the vessel will move on. The other is the skeleton type with a hull made up of a number of lighters which will detach from the main hull at their particular destinations.

On rivers, containers can be carried by the katamaran type of craft, having two hulls and an interconnecting deck of a size sufficiently large for cargo handling, stowage and carriage.

* * *

With regard to society, transport fulfills a two-fold function and plays a two-fold role. On the one hand, it is an industry which links all the other industries of the national economy into a production entity and moves products from makers to users. On the other hand, it is a service which is continually expanding because of the ever growing division of labour, rise in public welfare, increase in leisure time, and progressive urbanization.

While industrial transport of the future will be one of high capacity, specialized and controlled by automatic systems so as to satisfy the needs of the national economy to a fuller degree and save public labour, passenger transport should be capable of handling ever-growing traffic and offer the passengers the ultimate in convenience.

The ultimate in convenience implies not only convenient terminals, good lighting, air conditioning, comfortable seats in the vehicles and vessels, and proper servicing on the way, but also well-kept schedules, frequent service, and, what is most important, speed, that is, the shortest door-to-door time possible.

Thus, transport fulfills vital social functions by contributing to division of time between work and leisure and by affecting the degree and extent of man's fatigue, especially in the case of commuters.

From this point of view, it is especially important how fast transport is or, rather, how much time has to be spent on the entire journey.

The latter point is taking on an ever growing im-

portance because the discrepancy in speed among various forms of transport throws out of any reasonable balance of the time needed, say, for a passenger to reach an airport and the time he actually spends in flight. For example, a person wishing to fly from Moscow to Leningrad will have to spend two to four times as much time in going to and from the airports as in flight. However, speed cannot be increased without bound. There is an optimum speed for every form of transport in a particular stage of development.

As regards passenger transport, whether or not it pays to increase speed depends in the final analysis on how high the passengers value their time, and this in turn depends on how well off they are. The willingness of passengers to pay bigger fares because higher speed does cost more to keep will govern the likely rise in speed for all forms of passenger transport. Thus, the speed of transport depends not only on an increase in the power of prime movers or conditions of traffic. It is not unlikely that the technically feasible speeds will not be utilized completely in the future, should this entail prohibitively greater fares.

Yet, the rise in public welfare will keep speed rising; passengers will always give their preferences to speedier vehicles and vessels. This is why airlines are now taking an ever growing share of passenger traffic.

In the Soviet Union where transport is organized into an integral system, competition between its various forms is out of the question. Transport is developing so as to carry more freight and passengers at an ever decreasing cost in terms of money, labour and materials.

There have been attempts to project foreign achievements in speed into the future of Soviet transport. However, high-speed services are warranted if there are enough passengers to carry. In some cases, an in-

crease in speed may be unnecessary, because it will not serve any reasonable purpose, although it may be technically feasible.

On this basis some investigators fix an average speed of 100-150 km/h and a top speed of 200 km/h for railways without major overhauls of their tracks and structures. At such speeds, distances of 800 to 1,000 km (classed as reasonable distances for passenger traffic) will be travelled overnight, leaving day hours available for work or leisure.

If the passenger traffic flow should reach 40 million or more, it will pay to overhaul the railway lines and rolling stock so that the speed may be raised to 250-300 km/h.

These estimates have been confirmed by high-speed railways built and operated abroad. The electric trains on the famous Tokio—Osaka line 515 km long travel at a top speed of 255 km/h and a service speed of 162 km/h. The line carries over 60 million passengers a year, and the number keeps growing.

The electric trains on the New York—Washington line 362 km long travel at a top speed of 263 km/h and a service speed of 140 km/h. The turbo-engined trains on the New York—Boston line have a top speed of 274 km/h and a service speed of 100 km/h and carry 40 to 60 million passengers a year.

Further increase in speed over 300 km/h on railways and 50-60 km/h for river craft and sea-going vessels will need novel principles of propulsion and novel designs of vehicles.

In the light of the impressive achievements scored by Soviet scientists, aircraft designers and builders, we may expect that at the turn of the 20th century supersonic aircraft will fly at speeds of 3,000-4,000 km/h, and subsonic aeroplanes will go near-sonic and fly at about 1,000 km/h.

A very important feature of Soviet transport in the closing decades of the 20th century will be a sizeable increase in the number of private cars.

The advantages offered by the private car are great and unquestionable. It saves time, makes work easier, offers a wider choice of entertainment, and can take you on trips to distant places of interest.

Today, cars are turned out in large numbers by the Volzhsky and Izhevsky motor works and the greatly expanded and overhauled Moscow works. In 1975, they made about 1,260,000 cars between them. Car manufacture will expand still more, and by the year 2000 their number will run into tens of millions in the Soviet Union.

Different figures have been quoted in the press as regards the number of private cars that ought to be had in the USSR. Recalling that there are 435 cars per thousand population in the United States and over 200 cars in Canada, Australia, Sweden, France, Switzerland, and Great Britain, the opinion has been voiced that the figure for the Soviet Union will be 200 to 250.

Proponents of a different view stress the negative aspects of spontaneous growth in the number of cars in the advanced capitalist countries, such as traffic jams, snail-like speed, lack of parking space, heavy air pollution and excessive noise, and insist that too many cars would conflict with the spirit of socialist society.

However, the experience with car expansion in the capitalist countries can hardly be applied to the Soviet Union, because we are living in different conditions and have different traditions. And these differences are great, indeed.

Firstly, car expansion in capitalist countries has been uncontrolled; the huge car-making concerns flood

the market with relatively cheap cars without any regard for the traffic-handling capacity of streets and roads; car output is never coordinated with the construction of garages, town planning or other activities.

Secondly, public transport in the capitalist countries is no match to that in the Soviet Union both quantitatively and qualitatively, and the gap will grow still wider in the future.

Thirdly, there is a big difference in how population is distributed in cities and, especially, rural localities. In the USSR, cities are planned and built as large housing estates with a high population density, linked to downtown and industrial districts by high-capacity thoroughfares and public transport. In the rural districts, the villages are merging into town-like communities. All this does not look like anything in capitalist countries with their lop-sided urbanization and the great proportion of small scattered farms.

This is why, in order to avoid the pitfalls of car expansion, the output of cars should be kept in proportion to the capacity of city thoroughfares and car servicing centres, and be increased in step with the construction of garages and roads; on the other hand, public transport should be given priority in development so as to make a more frequent service, to reduce loading of the vehicles, and, finally, to do away with fares for all users.

In this connection, it may be noted that Soviet cities will hardly need computer-controlled automatic "taxi-train" systems using cabins into which car owners will have to change on their arrival in a city, an idea which has attracted so much interest abroad. If necessary, public transport will do the job better.

In short, planned car manufacture and well-organized urban public transport should prevent car saturation plaguing advanced capitalist countries.

As it is seen today, urban public transport of the future will mainly be using large and super-large buses, comfortable trolleybuses, high-speed trams, and underground railways.

However, progressive conurbanization and town expansion will undoubtedly spur the need for novel types of commuter transport, such as high-speed hovertrains and magnetic-suspension vehicles.

Mention should also be made of transport for vacationers. This may be trains which include both conventional sleeping and observation cars; coaches for long-distance travel; sea and river vessels complete with playing grounds, concert-halls, etc.

Thus, in the future the needs of industry and population in transportation will be satisfied by both traditional vehicles of greatly improved performance, and novel types basically different from them. These new types will give a new dimension to the country's transport system.

* * *

What is particularly characteristic of economic development in the Soviet Union, both at present and planned for the future, is the ever-increasing utilization of natural resources in the country's northern and north-eastern regions.

Experience has shown that the capital cost of projects in those localities is two or three times greater than that of similar projects in the already developed areas, and sixty per cent of the total is the cost of transportation.

The high costs of construction and operation arise above all from the fact that a workable transport system is actually nonexistent and that traditional vehicles do not fit the climate, terrain and soil there. Motor and rail roads would only be attractive economical-

ly in the country's central, southern, and more or less developed northern areas. In the undeveloped northern regions, where traffic flow is very scanty, while the climatic conditions are still more adverse, roads would not pay, nor could they be built at reasonable cost.

Because of this, freight and passengers in the cold regions should be carried not so much by rail, water, air, road or pipe, as by vehicles utilizing unorthodox principles of propulsion. These novel types of vehicles can link main-line transport with users and do carriage of their own. Among them are air-cushion vehicles, or hovercraft.

The air cushion on which hovercraft ride is produced by an engine-driven fan which forces air under the vehicle's bottom surrounded by a flexible curtain.

Hovertrucks lifted by the air cushion clear of the ground can carry up to 20 tons of freight, and can be used for prospecting, in mail service, as ambulances, supply carriers or rescue vehicles. They feature unlimited cross-country capability and high speed.

Hovertrucks with only part of the load taken off the wheels, crawler tracks or rotors can carry 50 to 60 tons of freight and serve as heavy-duty carriers or tow-vehicles for air-cushion trailers.

An air-cushion trailer is a large platform surrounded by a flexible curtain within which an air cushion is built up. It has a fan assembly to supply air for the cushion, a propelling power plant, and wheels for better stability and steerability. Air-cushion trailers can carry heavy and large pieces up to 800 tons over peat swamps, the tundra, or the semi-deserts of Central Asia. In the case of especially heavy loads, several hovertrailers can be teamed up into a train.

Preliminary calculations of transportation costs per ton-kilometre for the Tumen Region in Siberia have shown that they are 71.2 kopeks for wheeled trucks

and tractors, 90 kopeks for crawler vehicles, 136 kopeks for the MI helicopter, and 64 kopeks for hovercraft.

Hovercraft admirably fit into the overall pattern of progress in building and industrial construction. Of late, the trend in the Soviet Union and abroad has been towards assembly of installations from large prefabricated elements, and the use of large machinery and apparatus in power generation, chemistry and mechanical engineering. Because the Soviet transport system is lacking a special service and vehicles to carry such plant intact, it has to be taken apart at the works, moved to construction sites in disassembled form, and put together on the site under less favourable field conditions. Obviously, this adds to the cost of construction, impairs the quality of assembly, and introduces delays.

That hovercraft can successfully fill this need has been demonstrated by the British Hovercraft Corporation. They used a standard wheeled cargo carrier fitted with an air-cushion plant to take part of the load off the wheels, in order to carry a 155-ton transformer. The vehicle cleared all weak bridges and stretches of the motor road without a hitch. The money saved on this single run was more than enough to pay with for the unloader of the carrier.

Overwater hovercraft will also figure prominently in the Soviet transport system of the future for rapid transportation, especially in regions lacking other forms of transport.

Overwater hovercraft may be either those with a flexible skirt or those with solid sidewalls, or skegs

In the former type, all space between the base oi the craft and the water surface is fenced off by a flexible skirt. This type of air-cushion vessels is amphibious, that is capable of travelling over both land

and water, especially shallow water, and can be used in the cold season, thus providing service the year round.

In the latter type, the air cushion is produced within the space bounded by the craft's base, the solid walls (or skegs) dipped in the water and, partly, by the curtains at the bow and stern. Solid-sidewall hovercraft are simpler in design and easier to control. They can move over shallow water, but cannot travel over land as their sidewalls must always be submersed in water to maintain the air cushion.

Several prototypes such as the *Briz* and the *Skat* (both of the flexible-skirt type) and the *Zarnitsa* (the solid-sidewall type) have been developed in the Soviet Union, and commercial manufacture has already been started. Before long these high-speed craft travelling at up to 120 km/h will join hydrofoil vessels to serve inland water ways and passenger sea lines.

At present, intercontinental traffic is carried either by airliners flying at speeds of 850 to 950 km/h or sea liners travelling at 30 knots, or 55 km/h. The gap in speed between them may well be filled by hovercraft with a cargo-carrying capacity of 5,000 to 10,000 tons and a speed of 100 to 140 knots, or 185 to 260 km/h. However, they will see commercial service not until the early decades of the next century.

It appears more realistic to pin hopes on high-speed hovertrains or magnetic-suspension vehicles propelled along elevated tracks at 300 to 500 km/h by linear induction motors. Work on this form of rapid transportation, equally good for long-distance, commuter and airport service, is under way in the Soviet Union, the United States, France, Great Britain, the FRG, Japan and some other countries. Progress in this work to date has been such that we may well hope to see hovertrains in service in the near future.

* * *

To sum up, the unified transport system in the Soviet Union, as we envisage it at the turn of the 20th century, will be built around the main-line railways which will ramify into secondary links, organically combined with an advanced network of motor roads operating reliably between and inside the various regions and localities.

The unified transport system will also incorporate inland waterways so important as meridional links between the well-developed central and southern regions, on the one hand, and the country's north, on the other. There will also be pipelines to transport oil, gas, coal and ores.

The unified transport system will terminate at sea ports which will provide a link with sea-going ships, and the lines in outlying regions with limited flows of freight and passenger traffic, which will be served by air-cushion vehicles.

The unified transport system will include air lines operating within and outside the country.

This unified system will have a wide-spread network of terminals—railway and motor-road stations, air, sea and river ports amply equipped with powerful cargo-handling machinery, and linking the various forms of transport to one another, to industry, and to other users.

That is how we picture to ourselves the transport system of the future, brought to life by advances in the means of transportation and by the needs of the national economy and population in its services.

A STORY OF INFORMATION AND COMMUNICATION IN THE FUTURE

AS TOLD BY PROFESSOR

N. T. PETROVICH

12—071

Systems to exchange information had appeared on the Earth long before man invented telegraph, telephone or radio. In fact, they had existed several thousand million years before man himself. In those early systems, media for information exchange were the primitive living organisms which formed in the remote Archean period.

The point is that any form of life evolves above all by the reproduction of its species and through the capacity for self-regulation in the changing environments. These two processes would be unfeasible without exchange of information. In reproduction, hereditary information is passed down from parents to children; self-regulation needs information about changes in the environments so as to generate, on its basis, commands to the organisms to adapt themselves to the changed conditions of existence.

Later, living organisms had evolved into communities, they came to depend on means of biological communication between the individuals, or else these communities would not survive. Also through evolution, living organisms have developed to varying degrees the ability for location of objects and navigation and are widely using it to find food and their whereabouts.

In its blind search by trial and error, evolution has embodied a huge multitude of principles and methods in such systems for the interchange of information. Ants successfully use a "language" of smells. Bees do well with ballet pas. Dolphins and bats rely on ultrasonic locators to take their bearings and catch their food. Some snakes locate their pray by a kind of infra-red locator. The animal world widely uses also sound communication systems. Marmots post sentries to give warning of an imminent danger by a whistle. Fish living at extreme depths and in pitch darkness

use biological sources of light, complete with lenses, reflectors and diaphragms. They communicate by light pulses varying in duration and repetition frequency. We are still to "crack" their codes.

About a million years ago a being with rudiments of intellect made its apperance on the Earth. Later, it took on, not without grounds, the name of *Homo sapiens,* the Crown of Nature, the Summit of Evolution, and so on. This happened, however, at much later time. At the bottom rung of the evolution ladder, it differed but little from animals. It exchanged information by the same methods as animals: a gentle or a rude touch, mimics and gestures, and a very modest choice of inarticulate sounds. Such was the poor language used by the herds (or less offending, the communities) of our predecessors.

In their struggle for existence—collective hunting, collective defence and collective labour, these communities had to exchange information between the individuals. Gestures and inarticulate sounds were obviously inadequate. In the long run, they were supplemented by spoken and, later, written language. This had taken a hundred thousand years to occur.

As the planet's population grew, people scattered far and wide all over the globe. With this came the need for means to transmit and receive information over distances thousands of times greater than the human voice can span.

In this, man has used many things. Urgent messages would be delivered by untiring runners or messengers on dashing horses. The Indians in America would declare war on a neighbouring tribe by a combination of camp-fires; the rattle of a giant drum would pierce the African jungle; or pigeons finding their way in a manner not yet understood would carry letters.

Still, this was inadequate. Man needed information exchanged at a faster speed and on a larger scale.

A real breakthrough came with the discovery of electricity. Then telegraph, or transmission of messages over wires, was invented. For the first time in his history, man could relay messages over distances many times the line-of-sight distance. At first, he used simple codes like the Morse code. Then came letter-printing telegraph where messages need not be encoded for transmission and decoded upon reception.

The next step was telephone. Now persons miles and miles away from each other could converse comfortably. Today all this sounds trivial, but at the World Exhibition in Paris, people would stand in queues for hours only to say and hear a few words to and from another visitor as a proof of the invention.

Unfortunately, telegraph and telephone could only operate over expensive wires and cables. Nor was it possible to fling a network of wires all over the globe to connect all points. Wires were simply out of the question for vehicles and craft. The problem remained unsolved.

Rather, it had remained unsolved until signals were transmitted through space without any wires at all. For the first time this was done by Alexander Popov of Russia. That was the advent of radio. Its major distinction, so obvious today that we do not even notice it, was the absence of wires between transmitters and receivers. The invention had put at man's service a fundamentally new information medium, invisible to the eye, capable of travelling through space at the velocity of light—about 300,000 kilometres per second, and passing through almost any obstacle.

The advent of radio broke up the chains that were holding information to wires and cables and gave it

complete freedom. Now it could reach not only ground-based stations, but also ships in the far seas, trains, aeroplanes, space probes, and the other planets of the solar system. Extending Popov's idea, Soviet people were the first to set up communication links in outer space. Using them, an artificial earth satellite, the first in the history of mankind, relayed its position, and Yuri Gagarin, the pioneer of space conquest, conversed with the Earthlings.

Yet, even when used together, wire and radio communication cannot satisfy the ever-growing needs for exchange of information. The problem is especially acute as regards long-distance communication. Here Nature has played one of its jokes on man. The wavelengths that would be able to reach any point on the Earth (short waves) have a very low capacity, nor can they be used reliably at any time of day or year. In contrast, the wavelengths that have a huge information capacity (microwaves and light) can only operate within the line of sight.

A way out has been offered by artificial earth satellites. They have extended the line-of-sight limits thousands of times. Hovering high above the Earth, satellites remain within the line of sight over huge territories and can use both microwaves and light for communication. Several satellites suitably located at different points above the Earth will be able to communicate within the line of sight with one another and with ground stations. Equipped with repeaters, they can form a world-wide, or global, communication network able, at least in principle, to handle any amount of information between any points on the planet.

Advances in means for exchange of information have been accompanied by those intended to store it. In fact, the two processes are inseparable. For information storage is the accumulation of experience, of

knowledge, of what persons, generations and nations have been passing down to their descendants throughout history.

By recording or memorizing information in one way or another, we preserve it for the future (near or more remote, according to the storage device used); that is, we transmit it into the future.

In other words, while communication facilities transmit information in space, storage devices do so in time. When used jointly, they provide for the accumulation and exchange of man's knowledge and experience and a continuous evolution of civilization.

The first storage device, or transmitter in time, was the animal brain produced by many million years of evolution. Well-memorized hunting grounds, danger spots, shelters or watering places meant survival.

As he rose above the animals through work, man was quickly improving his brain and his ability to store information. However, the struggle for survival and work activity needed also other means of information storage, external to the brain. For this purpose, the Indians used coloured shells, the Inkas used the kipu, a system of strings and knots. Each kipu had a long main string to which were attached other strings with various knots and woven patterns differing in colour.

Man has also used pictures cut on stones; some of them have survived until our time. These pictures were the prototypes of graphical methods to store and convey information.

In the fourth millenia B. C. ancient Egypt invented hyeroglyphs, characters which were partly pictures and partly symbols. They could describe complete things or events, or represent syllables or sounds of speech.

However, a veritable revolution in catching speech for transmission in space or time came with the advent and development of alphabetic scripts, systems which have a separate character for each spoken sound. Writing media developed and changed too: clay tablets gave way to leather, this was followed by papirus, parchment, and finally paper.

The invention of book-printing was no less dramatic in its consequences. Man had found a way to accumulate his experience and pass it down to his descendants. That was much more reliable than songs, legends or knowledge conveyed by word of mouth.

More recently, photographs and motion-pictures were added to books. Packing a wealth of information, a colour 3-D film can take you on a safari in Africa, or a journey across the Antarctics to play with little penguins.

Different machines have been used to store speech and music: the phonograph, the grammaphone, the record player, and the tape recorder.

Fundamentally new ways and means for storing information became necessary with the appearance of high-speed electronic computers. To make computations, a computer must keep in its "memory" many things: rules for making operations, input data, constants, intermediate results, and output data. Different media can be used to store information: punched cards, storage tubes, electromagnetic relays, flip-flops, delay lines assembled from coils and capacitors, mercury delay lines, magnetic tape, or cores from ferrite (a material which has a square hysteresis loop). In some respects, these devices may well vie with the human brain, the wonder-child of nature.

Starting with inarticulate sounds and broken twigs to mark his trail in the jungle, man has come to use today both oral and written language, operate com-

munication links via artificial earth satellites, memorize and reproduce some time later huge amounts of almost any information. He has learned how to transmit information in both time and space.

If it is true that the Universe has more than one civilization, they may well stand on different levels of evolution. Obviously, their standing may be evaluated in many ways. One is in terms of the energy consumed. Energy-wise, ours is a poor civilization. In contrast, civilizations utilizing as much or even more energy than their suns can supply might be classed as super-civilizations.

In my opinion, however, a much better way to class civilizations is in terms of information, that is, the amount of information received and processed by an individual per day. In terms of this criterion, too, the Earthlings seem to be on the lowest rung of the giant ladder leading into the realm of super-civilizations and, probably, complete self-expression of each personality.

Poor as it is, however, the stream of information that is pouring down on every Earthling is dangerous already today. This stream takes in the ever-growing experience man has been accumulating since the dawn of civilization, that is all of science and technology, current information appearing in newspapers and magazines, conveyed by telegraph, telephone, radio and television, and a mammoth flood of fiction books, motion pictures, plays, music, and paintings. This stream is growing at a breath-taking pace. Some future-researchers believe that everything must end up in an information explosion where man will be hopelessly lost in the information he is generating: our civilization will be unable to utilize all information, and its advance will slow down.

This view has produced an image of an information volcano, with all information generated by mankind flowing out of its crater. It is only "breathing" today, throwing up some ash and hot gas, small streams of lava only occasionally flow down its slopes, and scattered geysers gush here and there. This is not an eruption, yet; it is maturing in the insides, and the volcano is giving us its warning as an underground rumble and light earthquakes. The future-researchers who have thought up this image are sure that an eruption is inevitable and depict the consequences as dramatic as those in Brullov's immortal *Last Day of Pompeii.*

The reader has every reason to ask whether such pessimistic forecasts have any foundation. To answer this question, we shall have to look into the crater. Before we do so, it will be good to pick some instrument to measure information.

* * *

Mathematicians and physicists have agreed that it is both convenient and logical to define the unit of information as an amount which halves our ignorance about some matter. This definition completely ignores the significance of the information thus obtained.

For example, we obtain a unit of information when we get an answer to the questions like those given below:

"Name the hemisphere with the tallest mountain".

"Northern".

"What half of the year do you prefer for a vacation— first or second?"

"First."

Or suppose a student is at a loss. His duty calls him to the lecture-room, but the thirst for adventure

lures him to the movies. How is he to make the choice? He tosses a coin: head, the lecture; tail, the movies. The coin falls with its tail up—the happy student goes to the movies.

In all these situations, there has been the choice of two outcomes having the same probability. Now we shall consider a more difficult case where we are to make a choice out of four outcomes of the same probability. Suppose you are to fix your vacation time accurate to a quarter of the year, say, the second quarter; then in the second example above one more question would be necessary:

"What quarter of the year do you prefer?"

"Second".

Here is one more example. Suppose a friend of yours has put a coin under one of four cups. How can you locate the coin by asking only two questions?

"Is the coin under the first or second cup?"

"No."

"Is the coin under the fourth cup?"

"No."

Now you can lift the third cup—the coin is there.

As is seen, where the choice is to be made from four equally probable outcomes, you need two units of information.

If the coin be put under one of eight cups, three units of information will be necessary to locate the coin. The answer to the first question would leave four cups; the answer to the second, two cups; and the third, the last cup. Without increasing the number of cups, the reader may well believe the table below is correct:

the choice of one outcome out of two	one unit of information
the choice of one outcome out of four	two units of information

the choice of one outcome out of eight	three units of information
the choice out of 16 outcomes . . .	four units of information
the choice out of 32 outcomes . . .	five units of information
the choice out of 64 outcomes . . .	six units of information,

and so on.

From this table we may deduce a very intriguing relation between the number N of outcomes and the number of units of information, I, needed to make a decision:

$$N = 2^I$$

Taking the logarithm of this expression to the base 2, we get

$$I = \log N$$

What we have derived is a formula which gives the amount of information needed. For the first time, it was deduced by R. Hartley of the United States in 1928. In words, it states: the information needed to make a selection out of N equiprobable outcomes is equal to the logarithm of the number of outcomes.

As you learned at school, a logarithmic function increases with increasing number very slowly. That is, the amount of information needed grows likewise slowly with increasing number of outcomes. If we extend our table to include a greater number of outcomes, we shall learn that with 512 likely outcomes we shall only need nine units of information to make a decision, and for $N=4096$, as few as 12.

The layman is sometimes surprised at the ease with which an experienced criminal investigator unravels a crime from the meager answers like "yes" or "no" he gets from the suspect. Of course, the logarithmic relation we have derived helps him a good deal.

If we put $N=2$ in our equation, we obtain the unit amount of information ($\log_2 2=1$) which has come to be known internationally as the bit (which is an acronym for the BInary digiT).

We frequently run into this minimum amount of information, the bit, in our everyday life. It is a sure bet that back at school the reader used to move his head for a "yes" or a "no" in an attempt to transmit one bit of information to his failing mate. It is no chance that this "yes or no" technique has taken deep roots in all our dealings. It makes imperative for the person interrogated to give a clear-cut "yes" or "no" and leaves no chance for the ambiguous "neither yes nor no", "rather yes than no", or "both yes and no".

The bit has valuable properties. It is the simplest and most reliable piece of information that can be transmitted over distances either by a nod of your head, by waving a hand, by voice, the report of a gun shot, the detonation of a charge, a spot of light from a mirror, a camp-fire, or a flare.

The bit is a sheer boon for wire and wireless communications. Simple to the extreme (for you only have to transmit a "yes" or a "no"), it readily goes through noise and interference, gives a longer distance range and leads to fewer errors.

Most electronic computers work in terms of bits, too—they are more reliable, simpler to build, and obey simple logic rules.

The most important thing, however, is that these simple and far-reaching "yes" and "no" signals (which may take the form of 0's and 1's, a "+" and a "—", or a mark and a space in communication channels) can be assembled into any message, however complex it may be (not unlike an architect who can assemble a masterpiece from common brick). Or, rather, any

message, however complex it may be, including speech, music or pictures, may be analysed into simple bits of the "yes" and "no" type, transmitted in this reliable form over a communication channel, and reconstructed into the original form.

Thus, when we transmit from a point in space to another point a signal which can take only one of two equiprobable values, yes or no, we convey precisely one bit of information.

Of course, the information transmitted is entirely independent of the form of carrier and the duration of the signal. The carrier may be sound, light, electric current, a radio wave, or a laser beam; and the signal may last a microsecond, a second, an hour, or a year.

How can we count the amount of information contained in, say, the Great Soviet Encyclopedia in terms of bits?

The Russian alphabet has 32 characters. To represent this set of characters in binary form, we may assign a combination of five symbols of the "yes-no" type to each character ($2^5=32$). To this we should add the ten numerals, the punctuation marks and other auxiliary characters such as parentheses, quotation marks, dashes, etc. Therefore, instead of five units, we shall use six-unit combinations.

Now open any volume of the Encyclopedia and count the letters, figures and other symbols on any page. An approximate count will be 6,000 characters. By transcribing this page in a binary alphabet (instead of the cheerless yes's and no's, we may use more attractive 0's and 1's), we would get $6 \times 6{,}000 = 36{,}000$ characters (using the same page and type size, this would take up six pages instead of one).

If all letters, figures and other characters occurred in texts at the same frequency, the amount of infor-

mation on one page of the Encyclopedia would be equal to the number of binary symbols, that is, 36,000 bits. However, as Claude Shannon has proved, if some symbols are more frequent than the others, the amount of information in such a text is reduced. This fact cuts down the amount of information on a page filled with only zeroes and units to about one-third (in the case of the Russian language).

In other words, one page of the Great Soviet Encyclopedia contains only 12,000 bits of information. Assuming that each volume has an average of 650 pages, it packs 7,800,000 bits and all the fifty-one volumes, around 400 million (4×10^8) bits.

Among the merits of the bits we have mentioned simplicity and reliability. In this sense, it is a friend of man's (and, perhaps, of other intelligent beings, if they exist). However, this friend may turn and, in part, has already turned, to man's foe. This is eloquently demonstrated by the exponential curve along which the population of bits grows with time.

They are so many that man may well go astray in this jungle of bits. Every day, millions of people are contributing to the common wealth of knowledge, and this wealth is expanding at a fantastic rate. Today, this depositary holds an astronomical number of bits. It is becoming much more difficult to find one's bearings even within a limited area of common knowledge.

The situation looks like that in K. Chukovsky's fable where a girl wished to have all toys of the world and nearly perished in their invasion.

* * *

Over the past centuries, exponential growth has been discovered in everything that can serve as a measure of the Earth's civilization—consumption of

energy and materials, population, scientific and technological information. What does it mean in plain language?

Imagine yourself at the summit of a steep snow-covered hill. You make a snow-ball and let it roll down the slope. On its way down, it picks up snow, and as it grows in size, more snow sticks to it, and the ball grows in size still faster. This is the rationale of the exponential law.

The law itself can be derived as follows. Let the letter y designate the mass of the growing snow-ball. Then the rate of growth will be a time derivative of mass, that is, dy/dt. To avoid higher mathematics, we may find the rate of growth by dividing the increment in mass, Δy, into the time interval Δt, during which it occurs, or $\Delta y/\Delta t$.

The exponential law requires direct proportionality at any instant between the growing mass of the snow-ball and the rate at which snow sticks to it:

$$\Delta y/\Delta t \text{ (or more precisely, } dy/dt)$$

Then the general requirement for direct proportionality may be written as

$$\Delta y/\Delta t = \text{constant}\, y$$

If this relation held for, say, the planet's population, a three-fold increase in its number would bring about a three-fold increase in the rate of growth. As a result, the total population would grow, and this growth would again entail an increase in the rate of growth, and so on.

If nothing stands in the way of expansion with this direct proportionality, it may reach any magnitude, however great.

In our example the growth of the snow-ball would be limited by the length of the hill slope.

If the slope is long (suppose you let a snow-ball roll from Mount Elbrus in the Caucasus), the mass y would grow so much that air drag would become noticeable, the snow-ball would slow down, the rate of snow pick-up, $\Delta y/\Delta t$, would drop, the growth of the snow-ball would slow down, and the direct proportionality would hold no longer.

It is natural to ask how the mass of our snow-ball should grow in time so as to retain direct proportionality between y and $\Delta y/\Delta t$?

Such a relation is expressed by a remarkable function which alone satisfies our requirement and remains proportional to its derivative for all values. It is written as

$$y = y_0 \exp(\alpha t)$$

where y_0 is the initial mass of the snow-ball at time $t=0$, and α is the constant whose choice depends on the steepness of the hill and the state of snow.

A graphic representation of this relation is known as the exponential curve. It is remarkable because it climbs at a snail's pace as long as the value of y remains small, but picks up speed as y increases, and finally sky-rockets at high values of y.

A quantity behaving like that is said to grow exponentially.

This curve kept its modest place in the huge armory of other mathematical functions and never suspected it would be given a great honour to describe the pace of the Earth's civilization (including mathematics itself).

Now its role has been discovered and its enigmatic name, the exponential function, has become popular and turns up now and again in books and magazines.

To Mass and Energy, the two whales that supported Newton's classical world, the last decades have ad-

ded Information, a third, no less powerful whale. Cybernetics and information theory have made mankind aware of this giant. No living organism can do without bits of information; no "thinking" machine can be built without the same bits to convey instructions and data; no communities of intelligent beings (above all humans and, as some believe, dolphins) and of animals (such as ants, bees and the like) would be able to exist without some sort of communication system. In fact, we may well treat the whole of the Earth as a single cybernetic system, as a control system with a huge number of elements (for example, every person may be looked upon as such an element), and with ramified feedback.

This is why we may define a civilization as a system seeking to derive a maximum amount of information about its environments and about itself, analyzing this information in abstract form, and utilizing this information to generate responses enabling this system to survive and grow.

Such factors as wars, epidemics and the like may be classed as temporary disturbances within the system, which will undoubtedly be in the long run done away with due to control and feedback.

This definition may be questioned, but there is no denying that the progress of mankind is based on a continuous process of acquiring, accumulating, transmitting and utilizing information.

No doubt, if this process were slowed down even temporarily, civilization would inevitably decay. Fortunately, in the many million years of ruthless struggle for survival, man has learned to forge ahead towards things new and unexplored, to improve his tools and himself. This is why the accumulation of information cannot be stopped. It goes on on an ever-growing scale, and this growth is exponential!

If so, a time may come when the growth would be along the steep part of the exponential curve, the accumulation of information would look like an avalanche and exceed any amount, however great. This would be an eruption of the information volcano. This would be the widely-prophecised information explosion.

Will this ever happen actually?

To get an answer, let us turn to facts.

* * *

We have already mentioned the sources that are pouring the stream of information on the Earth's inhabitants today. These are newspapers appearing in many hundred million copies a day; these are scientific books and journals, fiction books and magazines turned out in hundred thousands. These are over a half-billion radio sets. These are several hundred million TV receivers. These sources are growing in number much faster than the Earth's population (the latter, too, follows an exponential curve, but it doubles over a longer period).

There are limits to how man can take in information. On the one hand (if not too tired), he usually feels bored and even depressed if information is coming in slow. On the other hand, he may miss a good deal if he is fed more than 25 bits, or a word, every second.

No man can read more than two to three thousand books in his lifetime. In fact, this is a good performance. It can be achieved by reading about fifty pages a day. In the meantime, over 20 million books will be added. Thus, man can read one book in 10,000 on the average.

This figure is an overestimate, however. We like to read and re-read classics or simply favourite books. So the estimate must be reduced still more.

The gaping disproportion between man's capabilities and the huge stream of information present-day civilization dumps on him stresses the need for new ways and means to "pack" information so that it can reach every one through the narrow slit in his perception.

Is it possible to sort out the books, magazines, radio and television programs and any other information so as to leave only what would suit the tastes, desires, sentiments and aspirations of a particular individual? Some, ignoring the information volcano, pick up whatever comes their way. Others follow principles of some kind and try to learn a thing or two about books, films or plays from their acquaintances before they venture to "take in" anything. Still others make it a point to read book and other reviews first and make their pick afterwards (some read or see what is praised, others do the other way around).

Our concern, however, is with the accumulation and utilization of scientific information. It affects the progress of mankind most of all because it controls the principal factor in historic development—means of production.

A distinction of our civilization today is a rapid growth in the number of scientists. In the Soviet Union, the population doubled in seventy years, from 124 million in 1897 to 236.7 million in 1968. The number of scientists doubled in a mere ten years—between 1950 and 1960. It again doubled in a still shorter span of time, in five years, between 1960 and 1965. If we extrapolate this rate of growth in the number of scientists into the future, we would arrive at an absurd result—in eighty years from now all adults in the country should become scientists.

Taking the world as a whole, findings in science double in about ten years. The accompanying information, however, increases eight to ten times in the meantime. Out of this information "fertility" has arisen the bugaboo of a fire-breathing volcano about to erupt in an information explosion. For the amount of information doubles every three or four years!

At present, 100,000 journals throughout the world carry over four million papers every year. To this should be added tens of thousands of books, hundreds of thousands of patents and inventor's certificates. Incidentally, inventions today total an astronomical figure—13 million.

If we put all this together, some 1,600 pages is printed per engineer's or scientist's capita weekly. Even if this poor devil of an engineer or scientist were to spend all his time reading the literature on the subject, he would learn not more than one-tenth of the ideas advanced by other people without any hope to do work and propose ideas of his own.

This disproportion has already been responsible for heavy losses of information and heavy wastages of time and money only because a "wanted" idea has been searched for at random in the hope of running into the right thing. In the United States and Great Britain, some 10 to 20 per cent of all research and development work is duplicated because of failure to locate what has already been done. In the USSR, the share of duplicate "inventions" in the field of coal-winning machinery rose from 40 per cent in 1946 to 85 per cent in 1961.

This is how things stand today. But the exponential curve keeps rising steeply. If it is to follow the trend of the past decades, the information stream will increase 30-fold by the year 2000. The loss of information will then be crippling, indeed. This situation has

come to be known as "information saturation". If we liken information to food, in a situation like this man would appear as a fly trying to eat an elephant.

The advancing saturation of information and its resultant devaluation (because it can have any value as long as it is utilized) have forced some future researchers to speak of an inevitable stagnation in our civilization and a slow-down in technical progress.

* * *

Time has come to measure how much information man can store. Today, we can do this only approximately because the brain has just started to learn itself and a reliable model of how it works is still lacking.

Scientists widely differ in their estimates about the capacity of human memory. The figure quoted most often is 10^{12} to 10^{15} bits. How big is it? As we have already learned, all of the Great Soviet Encyclopedia contains 4×10^8 bits—a negligible fraction of man's capacity. The whole of Lenin Library in Moscow contains about 10^{13} bits of information. That is, all of it could well be packed in the memory of a single (yes, a single) person. However, nobody has ever run into a living library of such a capacity. Why?

The point is that on the average man can take in information at a rate of about 25 bits, or one word, per second. At the input rate like that, an individual who sets out to fill his memory full by working ten hours a day during 70 years would only have taken in 3×10^9 bits at the most (even if he forgets nothing). This would be about one-thousandth of the total capacity if it is set at 10^{12} bits, and not over one-millionth if it is set at 10^{15} bits. In other words, man utilizes an extremely negligible fraction of his brain's natural capabilities.

We can only make a guess why natural evolution has built so large a safety margin into man's memory. However, this margin exists, and man will finally learn how to tap it. In fact, some approaches have already been tried. One is fast reading.

By absolute standards, as we have learned, people are slow readers. Yet, they differ widely in reading rates. Some gulp books by taking in a hundred words or more within a minute; others plod along through weeks or more. However, there is nothing to prove that slow readers retain and comprehend the reading matter better.

Now it is a fact that the reading rate can be improved by exercise. During the second world war, British psychologists developed a technique (aircraft-spotter classes) by which people could be taught to identify enemy airplanes in an instant. Thousands of Englishmen could spot a German plane from a faint silhouette at a glance. This prompted some investigators to look for techniques that would teach people to read faster. For the first time this was done at Harward University in the United States after the second world war, and classes were organized for businessmen wishing to learn fast reading. Now, such classes are conducted at many factories, offices and firms in many countries.

A widely held opinion is that when a person reads his eyes sweep smoothly across the page. Actually, during an hour of continuous reading, his eyes remain fixed for an average of 57 minutes, and only move in the remaining three minutes. The greater the number of words the reader can cover during a stop and the better he comprehends them, the faster the reading. Precisely this goal is sought in training people to read fast. With appropriate techniques and simple gadgets (like a tachistoscope, or phase-flasher), your

reading rate can be stepped up five to ten times or even more.

It appears that fast reading should be started at school when children have not yet picked up bad reading habits (especially subvocalizing, that is, the tendency to form words with their vocal chords).

It is a well-known fact that a drawing, a diagram or a photograph will usually carry more information than a printed text taking up the same area. A person grasps this graphic information all at a time. This ability is mainly utilized in technical publications, but not to the full extent yet. In all probability, a happy combination of printed text and graphic matter can be found for each class of information and for each bracket of readers, to give a maximum rate of information input to a person's brain. Coupled with fast reading, this may raise the rate of information input tens or even hundreds of times.

As I believe, conventional books and journals will inevitably give way to novel types of publications combining printed and graphic matter. Our descendants will inhale them at an instant and update their information. Such publications will be the outcome of joint effort by authors and artists. It is not unlike that some people will work in both capacities.

Unfortunately, the brain cannot retain all information put in. The retention percentage is high where reading matter evokes vivid interest, an emotional upheaval or a feeling that the matter read is important. It is everybody's knowledge that our memory retains best what leaves a deep and lasting impression. Poor retention has the same effect as a reduction in the rate of information input.

A great many techniques have been developed to develop better retention, but they are seldom used. They, too, must be taught at school.

Speaking of retention, mention should be made of sleep-learning, or hypnopaedia. The idea is not new. Back in ancient Greece, teachers used to whisper difficult passages to their disciples while they were asleep. In our time, sleep-learning was used to teach Morse code at a US Navy academy in Florida and pilots in France. Later, sleep-learning came to be used in teaching foreign languages. It appeared that a new and highly efficient method had been found for information input, the more so valuable because it could be used during inactive hours. Deeper studies have shown, however, that sleep-learners could retain the subject matter only during the light phases of sleep, while the person is simply drowsy. As the sleep becomes deeper, the rate of information input is reduced drastically. In short, sleep-learning can only be used for a short span of time, when a person is not practically sleeping, when Morpheus has just stretched out his hands, but has not yet embraced you.

Yet, chances are that in the decades to come the bottleneck in exchange of information between its sources and man, that is, the low rate of information input into man's brain, will be removed, and man will be able to utilize the capabilities prudently built into him by evolution to a far better degree.

However, this approach alone cannot avert the information explosion. Let us see what other approaches are.

*

Thus, if the wealth of scientific information in the nearest decades is to grow exponentially, the outcome will be undesirable. Information will be produced in excessive amounts. Scientists will no longer be able to say what they do know and what they do not. Progress will slow down.

May we hope that the world around us has a limited supply of information and our knowledge will not follow the exponential curve, and that the information man unravels will diminish rather than increase?

No, such a hope is empty. The exponential curve holds for both knowledge and the new problems that arise from it. The problems that lead to further problems in the course of solution are called fundamental or basic.

Nature shows an infinite and unbounded variety. In Newton's words, nature is inexhaustible in its inventions. This is immediately borne out whenever we peer into the bottomless world of the atom or the limitless expanse of the Universe. So we had better leave all hope that the information stream will ever reduce to a trickle.

Can present-day science and technology help a scientist or an engineer to find the piece of information he is looking for in this growing swell? For the crux of the matter is "How to find?"

To recall once more, an average person can comprehend and retain information at the rate of not more than 25 bits per second. This is where cybernetics can prove its worth, especially its tools, high-speed electronic computers. Today, digital computers can handle more than a million bits per second. They may well take the brunt of the information avalanche and mete out to man only what he actually needs. (Of course, for this to be done, computers must form a union with a global communication system). Everything appears to be simple, but—

A big snag in this matter is that man and machine use different languages. Man uses letters, and the computer numerals. Human alphabet uses (in the case of the Russian language) thirty-two letters, and that of the computer only two numerals: 0 and 1.

All human sources of information—articles, books and reports—are written in a human and not in a machine language. Therefore, if we are to utilize the huge memory of the computer and its ability to retrieve any information almost instantaneously, this information must be translated into machine language. But, again, it would be only half the job done. Because, output data must be translated back to a human language.

A short-cut to implement such a scheme is to computerize libraries and to replace the conventional file cabinets with electronic reference computers which will give the reader a faster and better help.

I usually feel despondent and exhausted after several hours of search in a multitude of library catalogues (systematic, alphabetic, subject and a couple of auxiliary ones), looking up hundreds of cards in semi-darkness (a strange tradition of almost all libraries), only to find that the article I need most is not there. Surely, I am out and out for libraries to be computerized as soon as possible.

Early steps have already been made both in the Soviet Union and in other countries. A computerized catalogue has, for example, been installed in the US Congress Library.

Information-retrieval computers (as they are usually called) will select and keep records of all publications, class them by subjects and in any other ways, make them available to users and, what is most important, answer readers' requests to a fuller extent than existing library catalogues do. Readers will be able to key in their requests at a reader's terminal, and the publications they are looking for will be displayed either on a kind of television set or turned out as hard copies. The reader will have a choice of reading the article right on the spot or taking a copy home.

With, say, 200 such terminals a computerized catalogue will be able to converse with 200 readers at a time "quietly" (the quotes stress the fact that millions of bits will be flashing through the computer in the meantime).

Far more revolutionizing ideas are being discussed as a way of averting the information explosion. One idea questions the value of the traditional methods used to accumulate and store information in the form of journals, books and other printed matter. According to this idea, all information stored in computer memory, microfilms or any other space-saving media should be held in a new type of libraries where no readers go and the number of personnel is kept to a minimum. A reader will be able to send a request for a book or article by telephone and then read it on his video monitor at home. An internal memory will store it for repeated use or for copying.

How can we possibly do without books, the reader may ask? Many people like to leaf through a favourite book once in a time, put it under the pillow, take along on a business trip, or stow in the rucksack when going to the mountains.

I must admit the new techniques may look or sound blasphemous to book-lovers. To allay their fear or indignation, I may add that in the future some combination will undoubtedly be found for the new and old methods of information storage and transmission and the book will retain a pride of place among them.

Thus, the threat of imminent "troubled times" when excess information will break up all ties between individual scientists and between their teams is obviously exaggerated.

Firstly, high-speed and super-high-speed computers are coming to man's rescue.

Secondly, we know from history that the exponential growth of a process is usually terminated by some changes in the external factors. In the 19th century, for example, the number of horses in the world was growing exponentially, and fears were voiced that in the 20th century their number would be over 10,000 million and that all people were doomed to become stable-attendants. Nothing happened, however, because railways, automobiles and airplanes have ousted the horse.

A similar situation is taking shape in some big Western cities overcrowded with cars. If their number should keep growing exponentially, all roads and streets would be completely congested and all urban inhabitants would die of suffocation by exhaust gases. However, the growth curve is now beginning to level off. Many newspapers are carrying ads which praise bicycles; in fact, many people tend to give preference to bicycles before cars (bicycles are smaller by comparison, give off no exhaust, speed of travel in congested streets is about the same, and the rider receives a good physical exercise on top of all).

The exponential growth of information does not seem to be essential to the further progress of science. Linear rise would do well, especially if we apply rigorous filtering to all information and discard repetitions, compilations and any other publications carrying no new ideas.

Now to sum up. The imminent information explosion has so far been felt as a continuous growth of the information stream. In the future, this growth will apparently continue, but along a quiet rather than an exponential curve. The wide use of computers in information retrieval, information filtering and some other measures will help to keep the growth of information under control and at a safe distance from an

eruption, although the information volcano will go on seething as long as our civilization exists.

Now let us have a look at the part that information transmission systems can play in controlling the information explosion.

*

The increase in the size of the global information stream in the form of conversations, messages and reports has always been accompanied by a commensurate expansion in the handling capacity of communication facilities and improvements in transmission reliability (we no longer have time to repeat messages). But communications systems can do more than that. They can keep the snow-ball of information under active control and relieve man of some burden so as to give him more time and effort for creative work.

Today, a researcher has to waste a good deal of time in the search for a publication he needs: he leafs through the catalogues of more than one library, turns upside down his own library, questions the experts in this particular field (by telephone or personally), turns to the patent service, and so on. In the words of an investigator, "I'm working like a whale screening the plankton out of the water". Exhausted by the search, the investigator often tries to handle a task or a problem as a whole on his own, ignoring what has been already done by his colleagues.

Now picture to yourself how all this may well look like in the future. At your elbow is a visual terminal. You dial the number of the Central Information Utility, state your request (using, apart from your voice, also your mimics and gestures) without the need to fill out request slips (which are usually done in triplicates) and sit back ready to view the data you need

on the video monitor. Or, simpler still, you dial the code of your problem by phone, and the flashing bits in a super-fast computer will do the job for you by displaying the matter on the screen—you read it and enjoy. That is how a lot of time, effort and money can be saved in tackling any scientific or technological problem.

To be transmitted faithfully to the millions of users at research institutes, offices, factories or private homes, this huge stream of information needs communication channels having an extremely large bandwidth and fantastic sending speeds (tens or even hundreds of millions of bits per second). Within the limits of a city, that is, within the line of sight, this job can be done by decimetric (UHF), centimetric (SHF), millimetric (EHF) and even optical wavelengths. As already noted, these bands are extremely roomy and can handle thousands or even hundreds of thousands of television channels each.

Unfortunately, these waves will not bend round the Earth and travel any further than the line of sight distances. This is where sputniks have held out a helping hand. Even within the line of sight distances, communication satellites can give coverage to about a third of the Earth's surface area. With a microwave transmitter packed in a satellite, we are in a position to send a mammoth stream of information to all surface visible from it.

For the whole of the Earth to be covered, we would need three satellites as a minimum. Carrying retransmitters and coupled by links from sky to earth, from earth to sky and among themselves, such satellites would make up a world-wide communication system with capabilities to handle all information we may need, both for communications and broadcast purposes.

Before such a system can be built, quite a number

of problems will have to be solved. For example, reception of signals from communication satellites of the MOLNIYA type calls for the use of a parabolic antenna more than 20 metres in diameter, steered to track the satellite during its motion in orbit. From such an antenna, the signal goes to a receiver for processing before the signal can be distributed among users over the conventional networks.

Obviously, this type of system cannot serve the purposes of an information utility. Before any user can receive information directly from the satellite, the system must be made far simpler and less expensive, and the transmitter in the satellite must put out far more power. The MOLNIYA has a power output of 40 watts. So that your home antenna can pick up signals from the space-borne transmitter, this power output must be beefed up at least a hundred times. This is why the solar batteries now feeding the MOLNIYA and other communication satellites will have to give way to novel types of supplies.

It appears that an answer lies in nuclear-power generators installed on board satellites.

Even then, with a satellite transmitter putting out several kilowatts of power, your home antenna and TV set will need some changes so that they can pick up and display the signals from a satellite hovering thousands or even tens of thousands of kilometres away from your home. The point is that for better utilization of the satellite's power supplies or, which is the same, for a greater signal-to-noise ratio at the point of reception, transmissions from the satellites should use far higher frequencies than those used in the conventional TV networks, and modulate the signal on the carrier in a more effective way. This is why your antenna must be designed to pick up entirely different frequencies, and ahead of your TV set there must be

an adapter to convert the satellite signal into the conventional one.

Research and development work on direct TV systems like one outlined above is under way in many countries. According to UNESCO sources, plans are afoot in the United States to put in orbit a satellite carrying electronic gear for direct colour TV broadcasts. Several hundred receivers will be made specially to receive these experimental telecasts.

In contrast to broadcast systems, a major difficulty with communications system is the coding of messages. Any message must reach its, and only its destination, however far away it may be from the sender. This would be an easy matter if both senders and recepients were few. The problem is formidable, however, when they run into thousands or hundreds of thousands, scattered all over the globe, and when their working hours are all randomly different. Fortunately, information theory and cybernetics have some tools to do this job.

Thus, we have got everything, at least in principle, to build an information utility not only on a national, but also on an international basis. Equipped with the means we have described above and using satellite communication links, it will be fit to hold back the "exponential" menace.

Researchers will not be alone who stand to win from these novel systems. Any person on the Earth will be able to set up a connection with any one else. The videophone (local, trunk, international or space) will save you all the trouble of travelling, personal meetings and letter-writing. World-wide television will keep you posted on all happenings on the planet, help learn foreign languages, and give you a better insight into the cultures of other nations.

A big impetus will be given to personal radios. Using a transceiver the size of a match box or even

smaller, you will be able to keep in touch with your workmates, be it in an office, at a factory, or on an expedition, without being hitched to telephone. The same "match boxes" will be able to hook you up literally on the walk to the global network via a local communications centre. Or this may work the opposite way: your midget transceiver will give out a "bip-bip", inviting you to the nearest telephone office or alerting you to stand by for a direct call from the global system by radio. This, too, will save a good deal of time and effort and will do your work more efficient.

Thus, it is not at all unlikely that the nearest decades will see an integrated information field at work around our planet, based on a global satellite communication system and local networks. In contrast to the natural magnetic field out of man's control (yet), this one will be tame, packaging and forwarding information in whatever amounts it may be needed to whoever may request it. The unified automated communication system currently under development in the Soviet Union will, too, make its contribution.

* * *

In the future, the communication system on the Earth may be imagined as a system of giant streams of information flowing from country to country, from city to city. Diverging into smaller streams, information will reach all communities, and its rivulets will enter every home. These will be powerful streams, but what will be most important is that everybody will be able to adjust his own "information outlet" for output and content.

Today, moving to a new home or flat, the first thing you do is to check the supply of electricity, water and gas (the telephone, radio and television usually come

next). In the future, the top item on this check-list will be the supply of information. Perhaps, you will choose to have a separate room set aside for large video displays adjustable for size at will. These displays will reproduce any information you may want in solid relief and full colour, with all the scents and smells (and, perhaps, with something for four fingers to touch and for your palate to taste).

Information to these communication centres will be conveyed by waveguides and light pipes capable of handling huge amounts of various data. The rivulets of information entering every home will make your life far easier: you will no longer be forced to waste time searching for a piece of information, and cut down the time you usually spend on trips downtown, to other cities or even countries.

The impact, as I believe, will be strongest in the field of education.

Firstly, education by correspondence will gain more ground and take a stronger hold. Sitting comfortably in your favourite arm-chair at home, you will be able to listen to the best authorities on any subject as if you were actually present in the lecture-hall, and do so at the time of your liking because lectures will be all pre-recorded and played back on request. Something has already been done in this direction—before long you will be able to buy an adapter to your home TV, which will play back video records. These may well be lectures needed for students of correspondence courses or any one who wishes to learn something new.

Secondly, "canned" lectures will surely cut down the number of "live" ones at normal colleges and universities, and they will be of best quality.

A real breakthrough in the educational field will however come when teaching computers will be used to meter out information.

It is a well-known fact that the best combination is when a good teacher chooses an individual approach to each of his students. This includes an individual rate of progress and an individual manner of presentation, adapted to a student's ability to comprehend and retain the material. Unfortunately, the existing system and mass scale of education offer little in this respect. Working in an assembly-line manner, our colleges are forced to set their pace to accommodate the so-called average student. Not infrequently, the lecturer can see an able student who has time to do several things at a time: take notes, grasp the subject matter and read a detective story on top of that, and an embarrassed weakling who has barely enough time to scrible his notes, let alone understand what he is jotting down.

Where lectures are read to large audiences, feedback in the teacher-student system is usually lacking. The rare laboratory classes and examinations cannot give a constant watch on the students' academic progress, and this cannot simply be done at lectures.

Some headway has been made since the advent of "automatic examiners".

Suitably programmed, a digital computer can teach tens or even hundreds of students on an individual (adaptive) basis, and do that much more efficiently. The teaching computers may well cut down the term of instruction to one-half or even less, leaving the graduates more time for keeping pace with latest advances in science and technology, that is, moderating the information explosion.

The cool attitude noted lately towards the idea of using computers as teachers arises, as I believe, from the fact that we have neither truly adaptive computers nor satisfactory programs for such teaching. It is beyond any doubt that they will appear before long.

It would be wrong to think that the computer will completely oust the human teacher. This will never happen. No contrivance, however clever, can replace man where words of mouth, and not machine words, are essential or where people are taught how to pass knowledge on to still other people. The teacher will stay, but he will be doing a more responsible and more critical job—that of compiling and updating programs for adaptive teaching, contributing what no computer can give.

Thus, the rich information field produced by relay satellites in a union with ground-based wideband communication channels and teaching computers will markedly speed up education, shifting it to our homes and relieving us of the need to spend time and effort on trips to and from college.

Self-education will be extremely popular. Whenever you feel interested in some matter, you will be able to set up the code (number) of the subject on your home keyboard terminal and receive an introductory lecture on your visual display in an instant. If you wish to get a deeper insight into the subject, the computer will help, too. But you will have to apply yourself to study in earnest rather than be half asleep as this sometimes happens at lectures today. The computer will feed the material in a logical sequence and in portions adapted to your abilities, but it will at the same time be strict in checking your progress. The machine will be relentless in asking questions and setting problems, and you will have to answer and solve them promptly. True, every next step will come only after the computer is sure you have been good with the previous one (which is not the case very often today). In short, the rate of instruction will be wholly dependent on your progress, abilities and, of course, desire.

* * *

Undoubtedly, establishing radio contact with an extraterrestrial civilization would be the greatest-ever triumph for all of information theory, cybernetics, radio astronomy, and the science and art of communication. The very reception of a meaningful signal, that is one that could not be formed of its own accord, would be an extremely important milestone on the road of our civilization, even if we may fail to decode it.

Man will have learned he is not alone, that mankind is not unique, and that outer space is inhabited by other beings.

If this ever happens, young people will rush to find a place in the "contact" sciences. Apart from communication, cybernetics and radio astronomy, these sciences will include biology (to study the origin and evolution of extraterrestrial life), sociology and social forecasting (to trace the ways of the newly discovered civilizations) and linguistics (to decode extraterrestrial messages).

If we unpuzzle their languages from the received signals and samples, if we read their messages, reconstruct their image and ways of life on a TV screen (let it be a black-and-white one) on the Earth, this would have a far-reaching effect on the future of our civilization.

The last words are echoing the opinion voiced by the participants in the first USSR-USA conference on extraterrestrial contact, held at Byurakan (Soviet Armenia) in the autumn of 1971.

The conference stated that the advances in terrestrial science and technology over the past decades provide a sufficient basis for launching an attack at this problem challenging everyone.

Of the likely ways and means to establish contact, it appears most realistic to use radio waves, the laser beam, or X-rays.

But we are still very poor in terms of energy supply, and we cannot "hail" the millions of stars at full voice yet. Our "Ahoy!" would only reach the nearest stars, and the chances that they are inhabited by intelligent beings are scanty (but not zero). What remains for us to do now is to search the sky with radio telescopes in the hope of picking up signals beamed onto our out-of-way galaxy by civilizations far and far ahead of ours. You may ask if it is worth while trying, for it may well turn out there are, and can be, no such signals because there is nobody to send them?

There is a strong body of opinion, especially among astrophysicists, that intelligent form of life is not confined solely to our planet. So there must be signals.

Billions upon billions of stars surround us. Many of them have planetary systems of their own. The great variety of environmental conditions on these planets rules out any thought that life could arise and evolve to an intelligent form (by our standards, of course) solely within the system of only one lucky star, the Sun, and on only one lucky planet, the Earth. Because these stars differ widely in their histories and in the time of a stable existence so important to continuous evolution, various levels of civilization may well exist at the same time. Along with civilizations like ours, there must be super-civilizations which have since long done away with our vices: wars, oppression, infections, drunkenness, and so on, and have advanced far ahead. It is natural to think that they should hold out a helping hand to their kin in intelligence. This helping hand may be the information-packed electromagnetic carrier wave that we must intercept and guide to our planet.

Sceptics may argue that little could be gained from such information. For one thing, we might fail to read it or, if we read it, we would not be able to utilize it.

In my opinion, information would be immeasurably more valuable than any artifact from a foreign civilization.

The power of information is aptly described by Arthur C. Clarke in his *Previews of Tomorrow's World.* He advances the idea that material objects could instantaneously be transferred from one point in space to another by means of information alone. For any object is no more than but an orderly arrangement of a definite number of atoms and molecules. Then, if this information is read at one point and transferred to another, the only thing left to do is to replicate the original structure from the information received, and the material object will have been moved in space. We may question Clarke's belief that the wide use of replicators would ever replace the manufacture and shipping of goods, but the idea as such merits attention. This is especially so where information will be exchanged between distant civilizations, where material objects could not be transferred bodily by any other means.

Work on theory and hardware for such systems, however primitive they may at first be, appears intriguing. It is a real challenge to young people eager to apply their resources and free from bonds of traditional thinking.

As to understanding between civilizatioins, the fact that the sender and the recepient possess intelligence and that the Universe is governed by similar laws (with a few qualifications that we omit here) is enough for both to learn each other's ways and to exchange information.

In his *Previews of Tomorrow's World*, Clarke offers a time schedule for space exploration. Some of the events have taken place earlier. For example, man landed on the Moon several years ahead of Clarke's forecast. According to Clarke, extraterrestrial civilizations will be contacted in the year 2030. It is safe to say that this event will occur earlier as well, especially now that the USSR and the USA, the world's leaders in science and technology, have agreed to cooperate.

Apart from the search for signals from extraterrestrial civilizations, it is equally important to explore the planets in the solar system, to see if there is life and intelligence there. Among other things, this goal figures prominently in the space programs of the Soviet Union and the United States. At the time of writing, the Americans set their sights on the following goals:

Landing on Mars: 1981-1983.

1. Start from an orbit around the Earth: February 12, 1981.
2. Arrival on Mars: August 9, 1982.
3. Landing on Mars.
4. Start from Mars: October 28, 1982.
5. Flight past Venus: February 28, 1983.
6. Return to Earth: August 14, 1983.

These words are short, but thrilling. The other planned space missions include unmanned flights to the remaining planets Jupiter, Saturn, Uranus, Neptune and Pluto.

Before the end of this century, man will have explored all planets of the solar system and we shall get an answer if there is life on them.

The answer will be brought in mainly by tireless bits. In doing so, they will have to travel many billions of kilometres in space, penetrate giant accumulations of cosmic dust, traverse radiation belts, and clash

with cosmic radiations. Can our bits cope with the mission? Surely, they can, for they are guided by intelligence.

* * *

Now, to sum up.

It is true that the stream of all kinds of information, not only scientific, is building up with time. The build-up is following an exponential curve, and we have already reached its steeply rising part. While scientific findings are doubling every decade (or even every two or three years in the most vital areas), the amount of scientific information is doubling at a much faster rate.

This growth of information has suggested to some future researchers the gloomy picture of a fire-breathing volcano. We have taken you, the reader, there. Have you seen any real threat that this volcano is about to burst in an all-destroying eruption?

To tell the truth, there is—some. In fact, such an eruption may take place on the condition that the snow-ball will keep growing as it is doing now, that is, in an exponential manner, and that people will be taking in this information as they are doing today.

But the prophets of a new Pompeii are missing a very important factor—any community of beings, the more so intelligent beings, is a complex cybernetic system, and as such, it has the property of self-regulation and the ability to adapt itself to changing conditions. In our case, the change is the growing roar of the information volcano. Of course, if a cybernetic system is too sluggish in its response to changes in the environments, it will fail.

From what we have learned, we have no reason to believe that people will be too slow or too lazy in taming the volcano. In fact, something has already

been done and further steps are being taken in several directions, and new paths have been mapped out to be followed in the near future.

The task of prime importance is to put the volcano under control. Of course, any slow-down in the growth of information would lead to a dusk of civilization, as we have already noted. But there is nothing to prove that this growth must always be exponential. History has proved more than once that a process ceases growing exponentially when the factors driving it are changed. We have quoted the example of horses. Something like this will soon happen to cars.

We have named some ways and means of discarding superfluous information. Above all, only worthy material (carrying new ideas, presenting the material in a neat and crisp form) deserves to see the light of day. Any duplications, compilations, plagiaries and the like should be sent to dump. Instead of articles, journals should publish only their abstracts (with complete texts available to those who can afford to read them).

Any spent information must be erased by superimposition of so-called negative information, or negoentropy. The examples that follow will clear up the matter.

The discovery of the law of universal gravitation by Newton had brought with it a huge amount of negoentropy. Now everybody could use the same law, and a very simple one at that, to find the motion of celestial bodies instead of keeping their trajectories in memory and tables.

The discovery of the periodic law by Mendeleev removed all disunity between the chemical elements. From his table it was clearly seen that the properties of the elements were periodic functions of their atomic weights. In fact, using his table, Mendeleev predicted the existence of some, then unknown elements. It was

no longer necessary to keep detailed descriptions of the 63 elements known at that time, and the many classifications that had been in use prior to Mendeleev's discovery became useless.

Each time man combines seemingly different objects in a class, that is, establishes some relation(s) between them, he reduces the amount of information associated with these objects. No doubt, in its dashing progress, science will discover and establish ever new relations in the material world, thereby holding back the roaring volcano.

Secondly, man as the information user will enlist the assistance of systems made up of wideband communication channels of high transmission reliability and noise immunity, and high-speed computers. Nobody will any longer have to leaf through hundreds of journals, go through many catalogues, or read tens of reports of numerous conferences, simposia and meetings. Everything will be done by information retrieval machines in response to a dialled code number, including the display or a hard copy of the material.

If necessary, the machine will make a translation from one language into another (obviously poor today, it will certainly improve with time).

The time is round the corner when a global communication system will be set up on the Earth, incorporating communications satellites. With this system, any piece of information will be located in practically no time, using the world-wide video telephone service, world-wide television, world-wide newspapers (you will be able to get your copy on your home video display by pressing a button), a world-wide information utility, etc. This will leave much more time for truly creative work and for the assimilation of the continually growing information.

Thirdly, better ways will be found for putting information into man's memory. The most important thing here is to resolve the conflict between the low rate of information input and the huge potentialities of the brain of which man utilizes only a tiny fraction.

Some attempts have already been made. Among them is fast reading. We may also include sleep-learning, or hypnopaedia, although it only increases the amount of information put into man's memory, rather than speeds up the process. New combinations of text and graphics will be found for printed matter in order to raise the rate of input.

Of course, the problem can best be tackled by finding means for putting information direct into the brain, dispensing with assistance from the eyes and ears. New vistas will then open up before man in the accumulation of knowledge. For his brain is roomy enough to store all the wealth of information held at Lenin Library in Moscow. One may ask why all this wealth should be stored in the head; might it not do harm? Well, it is a fact that a person improves his performance in a certàin proportion to the knowledge he has acquired.

Fourthly, and lastly, the growth of information will bring about radical changes in education. Wideband communication systems with a user's terminal in each home will add much to the popularity of education by correspondence and self-education in any subject. Owing to large TV screens (colour, 3-D and stereophonic), the user will feel as if he is bodily present at a lecture, with the added advantage of being able to select the best lecture-halls of the world, or play back pre-recorded lectures by famous scientists and lecturers and be sure he is meted the best material and learns it in the best way.

Yet, however attractive these teaching methods may be, they will inevitably give way to adaptive teaching conducted by electronic computers. These will be ideal personal tutors; they will not make a step further until you have grasped the previous parcel of knowledge. They will keep tabs on your academic progress by asking questions, offering problems, and decide whether to pass on from your answers or simply from your emotional reactions. Prototypes of such "knowledge detectors" are already being tested. The pace of instruction will be set by students' abilities and desire to learn. Unfortunately, we cannot yet use individual teaching; instead, we adjust our progress to that of an average student. This equalization drastically reduces the effectiveness of instruction. As some investigators have shown, adaptive teaching can almost halve the term of instruction. As a result, graduates will have more time to follow the ever new advances of science.

This is not to say that in the future the student will be a sort of captive chained to a computer. Adaptive teaching will use a judicious balance of "live" words, the capabilities of the global information system, computer-controlled tests, and computer-supervised programs.

This system of adaptive teaching will help young people to choose vocations that fit them best. Today, this choice is often a matter of chance. I have asked many students why they preferred a particular college. The answers were different. Some did so because of their friends, others because the college was next block to their homes, still others because the competition was less stiff. Only a very small proportion could say they had made their choice because they were interested in the profession.

An adaptive teaching computer will be able to tell would-be students a thrilling story about various professions, and not only to tell, but also to prompt, through a series of tests and exercises, where a particular individual will do best and where his interest actually lies. In the final analysis, this too will arm individuals to fight back the onslaught of the information snowball.

Of course, the four lines of attack we have just discussed do not exhaust the problem (some of its aspects cannot be envisaged yet).

For example, we have not mentioned the reverse effect that the information volcano has on speech and publications. That this effect exists is beyond doubt. So far it has shown itself in the requirement to cut down the size or length of articles, books and reports. In the future, it will be felt much stronger. As a result, the informative content of oral and written messages will be increased: the same amount of information will be stated in a fewer number of words. This can be achieved in two ways. According to Claude Shannon, the greater the ensemble from which a word is selected, the greater the amount of information this word carries. So, every individual should build up his vocabulary. Room to do so is more than sufficient. Today, the vocabulary of the man in the street is one-twentieth of that used by Shakespeare or Pushkin.

The other way is trivial—we must teach every individual from his birth to express himself in a terse, clear and, of course, elegant manner both in speech and in writing. Lomonosov's motto, "Crowd the words to make room for ideas", should in the future be a rule for everyone. When practised, it will surely help drain the volcano's supplies. This will also save readers and listeners a lot of time and effort; paper, too will be saved tremendously.

Thus, the outlook of the nearest future, somewhere at the turn of the century, does not give grounds for fears that we shall fall victims to an information explosion, bombardments by megabit (million-bit) missiles, and the attendant slow-down of civilization.

The ways and means we have traced for curbing the volcano (computer filtering of information, augmentation of the brain's capabilities, improved information exchange systems, and better education) are a guarantee that the collective genius of mankind will cope with the problem.

Moreover, an information bridge may well be put across to other civilizations. This will add another information flow to those existing on the Earth—that from outer space. It will throw light on the great secrets of the civilizations that have moved far ahead of ours, and we shall learn from them how to curb and control the information Vesuvius in the most efficient way.

A STORY OF
MAN AND HIS ENVIRONMENT
AS TOLD BY
ACADEMICIAN
I.V. PETRYANOV

It is difficult to find a newspaper or magazine throughout the world which during the past few years had not published material on the severe damage which man inflicts on his environment, i.e., on the Earth's biosphere. It may appear that the public response to the ever-increasing pollution of soil, water and air has already exceeded, in scale, the problem itself. Probably during the entire existence of civilization no other problem has evoked such keen and, literally speaking, universal interest, such far-reaching and at times diametrically opposite opinions.

Professor Meadows, USA, is of the opinion that if the present growth of the population, industrialization, environmental pollution and the plunder of natural resources continues on the same scale, then the absolute limit of growth on Earth will be exceeded within the coming 100 years. This would lead to a rather rapid and unrestrained drop in the size of the population and production.

A British author holds quite a different point of view. He claims that the nature protection movement has caused more harm than good. The danger is not of a greater menace than those which had confronted mankind in the past. Typhus and cholera, these terrible disasters of the past, have practically disappeared in Western Europe. Diphtheria and tuberculosis have become rare. Do not these examples from history provide ground for hoping that the highly developed countries will succeed in coping, rationally and in good time, with the pollution of nature which today horrifies us?

In this controversy the paint on the picture thickens all the more and the utterances of politicians, scientists and journalists at times acquire an apocalyptical nature. We all wish to clearly realize whether this anxiety is substantiated. Has the situation really de-

teriorated so sharply? Perhaps man has suddenly grown wiser and begun to think about the consequences of his activities? Maybe the innumerable articles with their shrieking headlines are merely attribute to the time, while actually there is no special danger.

It stands to reason that every century, and perhaps even every generation, has its own "problems" and man has up till now coped with them rather successfully: otherwise life on Earth would have ceased long ago. It would, however, be unwise on this basis to fall into complacency.

The anxiety evoked by the pollution of the environment is substantiated and the situation has deteriorated over the last ten years. In addition we now understand better the intricate processes occurring in the biosphere due to our activities. It can be said in this respect that man has become somewhat wiser. Whether to a sufficient degree is another question which, apparently, may be answered by our grandchildren.

Not excluded are those people who wage the campaign against environmental pollution not according to conviction but to mercenary or other motives. This, however, causes no harm. The prevailing fashion to come out in defence of the biosphere is helpful, if this can in general be considered as being in fashion. Irrespective of personal motives, such utterances form public opinion, the realization that correct decisions on a very complicated matter must be taken.

* * *

In the first place it is completely wrong to attempt to compare our anxiety over the state of the biosphere with any other "world problem" of the past centuries. This is because not a single world problem has as yet

affected the very state of our world, the planet on which we live in its entirety, its surface, interior, all that live on it, the hydrosphere and atmosphere.

Mankind already globally influences nature by reshaping the land, by creating artificial seas and rivers, by changing the climate of entire regions. It would, however, be a gross error to consider that man was allegedly only engaged in transforming nature where primeval chaos remains into a more decorous state. Man, in transforming nature, introduces much greater disorder. He disturbs the equilibrium shaped in nature and this is the reverse side of civilization.

A continuous exchange of matter and energy occurs in nature with everything animate on Earth participating in the process. Plants absorb carbon dioxide, water and mineral substances and, using solar energy, form carbohydrates and other organic substances necessary for their life. At the same time they release free oxygen into the air. This process of enriching the atmosphere with oxygen has already been proceeding continuously for some 2,000 million years and there are no other sources of oxygen on Earth. The biomass formed from plants serves as food for herbivorous animals. The herbivora become the food of beasts of prey. After beasts die, their tissue decays and the matter, in one form or another, is again included in the biological cycle.

Such is the great closed cycle of life in nature. All its links function in direct dependence on each other. Man is one of these links. It is precisely man who strikes a blow at this ideally adjusted system.

People devastate forests and spawning grounds, permit overfishing, superfelling, overgrazing, etc. which in general can be called "overworking" (work which violates nature's income-and-expenditure equilibrium and undermines its restorative forces).

"We are waging the offensive against nature armed with all the machines and technology of our century, and we should be proud of this," I read in one of Moscow's papers. "It would be ridiculous to urge that today we return to the old primitive methods of lumber felling or fishing. Planes reconnoitre shoals and fishing is conducted by fleets of seiners and trawlers; forests are attacked by divisions of tractors and bulldozers, brush cutters and stump pullers, electric saws and skidding units. And nature? In reply, nature continues its restoration in the old and primitive manner, purely biologically. How can nature compete with the ever-increasing ingenuity and the technical equipment of its plunderers and offenders?"

These are bitter but absolutely just words. Does this mean that scientific and technological progress is a mistake on mankind's high road of advance, that it inevitably threatens catastrophe? Is this a mistake or, perhaps, an inevitable tragedy?

There are at least two diametrically opposite replies to this question. Some advocate a policy of "simplifying": others, that of further "complication".

Advocates of the simplification policy state: we are bungling matters, let's put an end to it. Let's turn back to the good old times, use horses instead of motor cars, build villages instead of cities. Let's live in houses built without concrete and brick, without elevators...

Mankind's achievements are so irrefutable that it is even awkward to seriously argue with advocates of such views. Suffice it to recall that scientific and technological progress (and the accompanying rise in culture) provides an enormous number of people with diversified and nourishing food, hygienic clothes, homes and an opportunity for intellectual development. Diseases, which for centuries have hounded man, are

in many aspects overcome, and medical science (with the medical industry being one of the branches of technology) has already prolonged human life for decades.

* * *

This, however, was achieved at a very high price. Jacques Yves Cousteau, a prominent oceanologist, had every reason to say: "In the past, nature threatened man, but today man threatens nature..."

We are, time and time again, making irredeemable debts as far as nature is concerned, squandering its assets, its age-old funds. True, all these loans were and are due to extraordinary circumstances. In the first place this is due to the requirements of mankind increasing with its numerical growth.

Indeed, there are very large numbers of people living on the Earth who have at their disposal such technological means and such methods of releasing and using energy, of spending the wealth accumulated in the depths of the planet and on its surface, that the need to subject the relations being shaped between mankind and the biosphere to a quantitative analysis and to draw appropriate conclusions from the computed correlations, is already obvious.

* * *

A prominent American demograph estimated that by July 13, 2116 there would even be no standing place on Earth for a new inhabitant. True, there are also quite a number of other estimates showing that the population, sooner or later, will cease to increase and stabilize on its own.

This, perhaps, may happen. Maybe another solution will appear in the future: for instance, man moving

to other planets may become a reality (such a solution has already been elaborated in detail by scientific fiction writers). Nevertheless, in the realistically near future, for instance up to the year 2000, no population stabilization can occur. Firstly, a considerable part of the present generation will live to the turn of the century. Secondly, the overwhelming majority of the parents whose children will appear up to the year 2000 already live on the Earth. Thirdly, the children born today or tomorrow will also have children of their own by the year 2000.

These simple estimates show that one of the main reasons for the unrestrained borrowing from nature, far from being eliminated, will be aggravated in the future. Hence, the problem should be tackled today as to how these conditoins must be adjusted to suit the planet's resources, if, of course, we wish to preserve our home.

The solution can be looked for along two parallel lines. On the one hand, by considering the maximum that can be taken from nature we should give tireless concern to the problem so that nature may unimpededly use its great restorative qualities.

On the other hand, we should energetically search for a means of existence independent of nature.

* * *

Probably the most complicated matter today is not the number of people on the Earth as such (only the largest cities are overpopulated) but to a greater extent, feeding these people.

According to the UN Food and Agriculture Department data despite a certain increase in the manufacture of foodstuffs (approximating three per cent whereas the rise in the population is only reaching two

per cent) more than half of mankind feeds badly and approximately one third of the Earth's population systematically suffers from malnutrition and hunger.

Here is the picture. Man's daily physiological requirements in food amount to some 3000 calories and his requirements in high-value protein, some 80 grams. These norms are even exceeded in North America and Europe while in other parts of the world they are not reached at all. In Pakistan the per capita daily average is less than 2000 calories with less than 50 grams of protein, and, incidentally, animal protein, the most valuable protein by amino acid content, hardly accounts for 25 per cent of this quantity. The average calorific value per person in Central Africa is approximately the same, while the consumption of protein in that region (also, in the main, vegetable protein) amounts to only 40 grams (this is half (!) of the physiological standard). These facts are from UN statistics and are cited by Professor Meadows.

The increase in food production is, mainly, accounted for not by the poorly provided countries but by those which have an abundance of food. Nobody has as yet claimed it feasible to provide in the visible future the necessary norm of some 3000 calories to all people in regions with a food deficit. One reason for this is the exhaustion of natural resources in countries with a rapidly growing population and where all the productive soils have already been used.

Our dependence on nature is to be seen to an even greater degree when examining the problem of mineral raw materials. The geological deposits of many metals are nearing exhaustion. The argument advanced that in the past deposits were found, they are at present also being found and this will always be so is unfortunately a misconception.

Practically, no "blank spaces" are left on the Earth: the structure of its crust has been sufficiently well-studied and important metals—which can be considered the foundation of civilization—can be found nowhere. During the past decades metal consumption is growing in an almost geometrical progression while the prospecting of new deposits or the re-evaluation of known ones only insignificantly increases the accessible mining resources. Apprehension exists that copper deposits, for instance, will at most last another 50 years, those of silver, perhaps 40 years, and lead, not more than 60 years.

All this, however, means that in the nearest future we shall need substitutes for the materials in greatest use; we cannot restock what we take from nature.

Naturally, fuel started civilization: without fuel there can be no fire. Academician N. Semenov has analyzed in detail the state of oil, gas and coal resources, extraction dynamics and the prospects for discovering new deposits. Suffice it to say that the estimates substantiated by world experts show one and the same fact: resources will be exhausted within 150-200 years, depending on the growth of extraction. Even taking into account hypothetic deposits, the exploitation of which is considered absolutely unprofitable, it is doubtful whether the top figure of 200 years will be reached. This is a very minute period when considering the prospects of civilization on a wide scale.

* * *

Man, entering life as a creation of nature, from the very outset, by his own will or otherwise, attempts to become all the more independent of nature. From the first implements created by man's ancestors, and especially the use of fire, when guarded and used consciously, the changes began.

Many brilliant minds pondered over this trend of development. Konstantin Tsiolkovsky, that great prophet and first theoretician of interstellar flights, wrote about a hypothetical being living in space and absorbing only solar energy. Tsiolkovsky considered the Earth as merely a large spaceship, a temporary home, a cradle from which man would some day take off for the expanses of the universe.

Academician V. Vernadsky, great scientist and thinker, expressed opinions, close in spirit but of a more specific kind on this subject. He pointed out that mankind would sooner or later become autotrophic (i.e., would be in a position of procuring food independently), would completely divorce itself from animate nature, completely cease to need it, and produce everything required for its existence independent of nature.

Mankind is actually, in a certain sense, advancing along this path. Some of man's vital requirements—requirements in food, clothing and shelter—are to an ever greater degree being satisfied independent of animate nature. We use synthetic materials for clothing, build houses of concrete and even artificial food is no longer a matter of fantasy.

In the past century M. Berthelot, a French chemist, predicted that in the year 2000 there would no longer be shepherds and ploughmen: chemists would produce food. And further: he said that the synthesis of foodstuffs from carbon (received from carbon dioxide), from hydrogen (extracted from water), from nitrogen and oxygen (from the atmosphere) will become feasible after cheap energy is obtained. When the land is no longer used for growing agricultural products, it will once again be covered by grasses, forests and flowers, will become a vast garden irrigated by underground water, in which people will live in

abundance experiencing all the joys of the legendary golden age.

Most probably, Berthelot's prediction will not come true by the year 2000, but this, in essence, changes nothing. Work on the development of synthetic food is being conducted in many countries. This, in particular, is being tackled in the USSR by a group of researchers headed by Academician Alexander Nesmeyanov. This, however, is another subject which goes beyond the scope of the problem under consideration. Nevertheless, the already practical possibility to synthesize in commercial quantities a number of indispensable amino acids cannot but directly bear on the problem of mankind's existence in the biosphere. Whereas it may, as yet, be too early to speak about "artificial chops", synthetic methionine and synthetic lysine, these major indispensable amino acids are now being produced in tens of thousands of tons. The large-scale industrial manufacture of vitamins is in progress. All this means that mankind has already entered the age of the industrial, non-agricultural manufacture of foodstuffs.

The manufacture (artificial!) of high-calory fuels (kerosene, benzine) which we are now inclined to consider as natural resources, atomic energy which occupies an ever greater place in the power economy of the industrially developed countries, and the attempts to master controlled thermo-nuclear synthesis—all these are attempts to overcome our complete dependence on nature. Nevertheless, something from nature is all the same used every time, considered as if it is "inexhaustible".

When people started to use coal and oil for the first time, they could not have had even the most remote idea that their descendants, we and you, would be anxiously considering how many more years oil and

coal would last. Uranium resources (in the form in which we at present see its extraction) are by no means inexhaustible. However, the tempting opportunity of creating "self-breeding" nuclear fuel has already been discovered, and breeder reactors are already in operation. The future of controlled thermonuclear synthesis is envisaged as something truly fantastic as the resources of heavy water in the ocean are almost inexhaustible. Even when taking into account the enormous increase in the consumption of energy, these resources will last mankind for at least 1,000 million years. However for the sake of a purely scientific approach, I should put the word "inexhaustible" in quotes.

Does all this mean that mankind is, becoming, or will in the near future become, autotrophic?

No, this is not the case.

I shall not deal with reasons so difficult to define why it is absolutely necessary from time to time for every person to simply breathe fresh air, go for a ramble in the forest, or lie on a sandy shore. All the manifestations of nature should be contemplated, be it the wild rocks of the Pamirs or willows on the sandy bank of the Oka river. I wish to stress another point: in the sphere of material production, too, man will not be able to manage resources created by animate nature for a very long time.

It, nevertheless, seems that mankind, disregarding its own opportunities and without noticing their limited nature, is making an all-out attempt to achieve this, as yet impossible, autotrophic state.

* * *

Technological progress alters the ways and means of the exchange of matter and energy in the biosphere. New types of industry have appeared during the past

100 years; the chemical, atomic, transport, engineering and pharmaceutical industries. This has brought into being new materials and new machines.

Numerous major processes are simultaneously taking place in the world. Mankind consumes water, uses an enormous number of chemical preparations, enlarges cities. All this taken together, all the forms of production—agricultural and industrial as well as the municipal services—put out not only useful products and goods, but also a gigantic amount of waste matter. This enormous mass of gaseous, liquid and solid wastes is ejected into the environment: on the earth's surface, into the air and the water.

The volume of wastes resulting from man's activities on the Earth is estimated at 5×10^8 tons a year. Those wastes contain so many chemical substances that their enumeration has already exceeded 600,000 items.

What is the result?

Man confronts nature with a most difficult and, at times, insolvable problem of processing these substances in its cycle. Nature, ever more frequently, finds it impossible to cope with this task. Cases of people being poisoned by nitrogen oxide, sulphur dioxide and mercury become more frequent. Smog suffocates people, pesticides and plant protective chemicals often poison not only insects but people as well: they are found in food and make it unfit for consumption. In large polluted bodies of water everything living is doomed.

* * *

Generally speaking, wastes as such are not so terrible. Animate nature, after all, has been endowed with huge means of defence. For instance, the self-cleaning capacity of natural water reservoirs is well

known. Organic substances in a river (and they can include leaves from willows growing on its bank, domestic sewage as well as part of industrial wastes) are excellent food for bacteria which oxidizing the organic substances decompose them. As a result, harmless mineral salts remain. Bacteria serve as food for infusoria, the latter—for larger fry: fish is food for man, and the mineral salts "fertilize" the river and are assimilated by algae.

Nevertheless, the self-cleaning capacity has its limits. When sewerage pipes of dozens of factories pockmark a river, no bacteria can cope with the industrial wastes. Another important point is the substances contained in the sewage: when toxic chemicals, strong acids, alkalies and phenols are dumped into a river, bacteria are doomed and no self-cleaning takes place in a dead river.

True, one should not forget the adaptability of life on the Earth. Evolution has developed the most diverse forms of life. There are, for instance, bacteria which even manage to live in hot concentrated acid solutions. Probably, within several millennia, such microorganisms could appear which would thrive in the most poisonous sewage, processing them at the same time into some harmless substance. Evolution, however, needs thousands and millions of years: as compared with its rate, those two or three centuries during which man carried out the technological revolution is only a minute point in time. Hence, one cannot count on the biosphere adapting itself quickly to the consequences of that revolution.

In exactly the same way there is no hope of man becoming "accustomed" to life in a poisoned environment or that our remote descendants will enjoy automobile exhaust fumes or find pleasure in bathing in sewage waters. Although, a man from Los Angeles,

the hero of one of Art Buchwald's satirical articles, while in the mountains is simply tormented by the absence of smog and offers a dollar to a passing driver for a whiff from his car's exhaust. This is only bitter irony on the part of a satirist. The real state of affairs places the dilemma: either people will arrange matters in such a way that there will be less smoke on the Earth, or smoke will bring it about that there will be less people on the Earth. These are the words of a distinguished Western scientist and it is hardly possible to sum up this matter shorter or more eloquently.

Thus, man for the first time for many thousands of years finds himself in a major conflict with nature. Let us examine the main spheres in which this conflict takes place.

* * *

To cite press reports:

... During the past 100 years 1.35 million tons of silicon, 1.5 million tons of arsenic, more than one million tons of nickel, 900,000 tons of cobalt, 600,000 tons of zinc and 600,000 tons of antimony were ejected into the atmosphere. In Great Britain, 1.5 million tons of coal dust, 2 million tons of ordinary dust and 5 million tons of sulphur dioxide are annually discharged into the air.

... A traffic policeman in the centre of London daily inhales gases as if smoking 100 cigarettes.

... Parisians breathe air capable of crumbling granite.

... US industry uses more oxygen than all the vegetation of that country can produce.

More and more such reports can be cited. They point to the fact that the state of the air of our pla-

net, including the fate of oxygen in the atmosphere, is beginning to evoke anxiety.

The use of oxygen is increasing at a gigantic rate. A plane burns from 50 to 100 tons of oxygen during a transoceanic flight. Every ton of coal burned consumes the annual amount of oxygen required by one person. A motor vehicle burns per 1,000 km the same amount of oxygen as a person breathes in a whole year. (Today there are more than 200 million motor vehicles on the Earth and their number is steadily increasing.)

It is most fortunate that as yet there are quite a number of countries which have not joined the monstrous race of destroying the planet's natural wealth. The air ocean has no political borders: the poisoned air of one country is diluted with the clean air of another country. This, nevertheless, has its consequences: after all, the volume of the atmosphere has its limits and its pollution is steadily increasing. In addition, the free circulation of the air in separate regions can be disturbed and in such circumstances atmospheric pollution can increase to such a degree that smog will literally suffocate people.

* * *

Throughout the world thermal electric power plants emit into the atmosphere several dozen million tons of ash and sulphur dioxide. Estimates show that if by the year 2000 the capacity of these power plants increase ten-fold, then even taking into account a certain improvement in cleansing, they will emit hundreds of millions of tons of sulphur dioxide and ash. The dust discharged by numerous industrial plants should be added to these millions of tons. The air is also polluted by agrochemical aerial treatment of the

soil, the spreading of fertilizers and pesticides. Dust is also the result of soil erosion. Atomic explosions eject into the atmosphere enormous quantities of pulverized substances.

In addition to all this one should take into account natural dust processes, such as space dust—about ten thousand tons of which annually fall on the Earth—as well as volcanic ash and the sands of deserts. The obvious result is that the Earth's atmosphere is being oversaturated with dust: at present there is 20 per cent more dust in the air than at the beginning of the 20th century.

Dust particles remain in the air from several days to several weeks. During that period they circle the Earth several times; radioactive dust remains in the stratosphere for several years.

What is the result? The air loses its transparency and transmits less solar rays; it is transformed into a screen reflecting solar radiation. If in the future the atmosphere is steadily and intensively filled with dust, our planet will ultimately become cooler, which may result in a new ice age. The planet Mars where lengthy dust storms rage in the atmosphere over its deserts can serve as a sad model for the future of the Earth.

* * *

The future may not only hold a drop in the temperature of our planet: overheating is no less probable. This may be caused by the excessive overheating of the biosphere. The industrially developed countries today produce almost the same amount of heat as that which we receive from the Sun. Besides, the carbon dioxide content of the atmosphere is steadily increasing, and this also threatens overheating. The annual

burning of fuel releases at least 10^{16} tons of CO_2 into the atmosphere, and the air also contains natural carbon dioxide released by volcanic gases, hot springs and the respiration of man and animals.

Carbon dioxide continuously circulates between the atmosphere and the ocean. During this process 60 times more of this gas is accumulated in the ocean than in the air. Green plants annually consume from the air some 160,000 million tons of CO_2. At the same time layers of limestones are formed in the Earth's crust. This is how nature functions but now changes are taking place.

It has been noticed that in many regions of the planet green plants suffer from malnutrition. At the same time the CO_2 content of the atmosphere increases during the past decade by 0.2 per cent. As yet, no scientific explanation for this plant malnutrition exists. This, however, is a sign that something has gone wrong with the biosphere exchange mechanisms.

The accumulation of CO_2 hinders the ability of the air to pass certain parts of the solar spectrum. The atmosphere becomes similar to the panes of a greenhouse which pass solar radiation, but prevent infrared radiation from escaping. This is known as the hotbed effect, which is vividly expressed on a global scale on Venus.

Estimates show that if the carbon dioxide saturation level is preserved also in the future, the content of this gas in the Earth's atmosphere will increase by 20 per cent, i.e., will reach 0.0379 per cent. This is already fraught with a rise in the temperature throughout the entire planet and may find its expression in the melting of glaciers.

Thus, on the one hand we have the spectre of cold and dusty Mars and on the other hand that of burning hot and lifeless Venus. Two diametrically opposi-

te trends in nature can be assumed—the Earth growing colder and it becoming hotter—which compensate each other, but science has not as yet confirmed this.

* * *

Let us now turn to another major sphere where a conflict develops.

"Our Father, the Ocean is dying"—this is how Jacques Yves Cousteau has time and again appealed to the world. Recently he wrote that the sea became a cesspool into which all the pollutants carried by the poisoned rivers flow; into which all the pollutants collected by wind and rain in our poisoned atmosphere fall and those dumped by poisoners such as tankers. Hence, it is not surprising that life is ceasing in this cesspool.

The French researcher is seconded by Thor Heyerdahl. During the *Ra-2* expedition he made the following entries in the log-book: "the degree to which the water is polluted is simply amazing"; "the pollution is simply terrible"; "at night waves throw on board the ship crude oil lumps the size of a fist. We discovered that algae, shell fish and even feathers from birds adhered to them". On May 31, off the African shore the following entry was made: "there is an incredible amount of pieces of asphalt covered with mussels; they are enormous, the size of horse dung, gathered in clusters. We also noticed a plastic bottle, a metal canister, a large coil of greenish rope, some nylon articles, a wooden box and a piece of cardboard. A terrible sight! How man pollutes the Atlantic ocean!"

Indeed, the ocean is being polluted with oil. Due to accidents 4×10^6 tons of oil have in recent years been spilt into the ocean waters. Oil, spreading on

the surface, forms a thin film. Such slicks spoil the natural exchange between the water and gases of the atmosphere; impairs the life of sea plankton which supplies oxygen and primary organic matter in the ocean. Sea animals suffer, birds perish. We still remember the tragic shipwreck of the tanker *Terry Canyon* off the British coast. That incident called the attention of people to the fate of the World Ocean and the need to take measures to protect its waters from oil. Nevertheless, the *Terry Canyon* disaster happened in 1967 while Thor Heyerdahl's notes were made in 1970.

In 1972, Jacques Yves Cousteau once again writes: "the Ocean is in danger!" He claims that "our ideas about pollution are most confused. Much is said about air pollution, water pollution and soil pollution, as if there are several types of pollution; but there is only one single pollution—water pollution. This is the case as all poisonous substances, whether emitted in the atmosphere or spread on the land, in the final analysis inevitably reach the ocean which thus has become the world-wide garbage dump."

And further: "...We, the inhabitants of the Earth can be compared with passengers on a ship who have received once and for all a definite supply of water. Even so, a ship in distress can hope for another ship coming to her assistance, whereas we are alone in the universe, completely alone with our small supply of water which is, as everyone knows, needed for life."

* * *

I shall not examine in detail the fate of inland water reservoirs and rivers which are in no less a disastrous position than the ocean. The wastes of gigantic chemical plants have transformed many of them

into sewage channels. Ferrous and non-ferrous metallurgical plants, oil refineries, cellulose and paper mills have saturated the water with ecological harmful substances. This can be observed everywhere in Western Europe and in the United States. Thus, already for many years, it is impossible to bathe in Lake Erie, one of the American Great Lakes. Divers describe the lake's bed as a "chemical laboratory waste-pail".

The case how the inhabitants of Alamogordo, a town in New Mexico, USA, were subjected to mercury poisoning is widely known. The poisoning was due to a high mercury concentration in tinned fish. The investigation showed that factories using mercury were continuously dumping their wastes into rivers and lakes.

A high mercury content is being found in the organisms of the Baltic Sea inhabitants. It is simply astonishing: mercury is even found in chicken eggs. Besides mercury and together with mercury such strong biological poisons as lead and cadmium are also found.

The greatest ecological harm is, however, caused by non-decomposing toxic compounds employed in agriculture as pesticides. They are washed out of the soil together with fertilizers, finding their way into shallow waters, into ponds and rivers, and further, into inland and external seas.

"How can the Earth stand this?" Walt Whitman exclaimed in horror.

I now re-read the lines from his "Leaves of Grass":

> "Now I am terrified at the Earth, it is that calm and patient,
> It grows such sweet things out of such corruptions,
> It turns harmless and stainless on its axis, with such endless successions of diseas'd corpses,

It distills such exquisite winds out of such infused fetor,
It renews with such unwitting looks its prodigal, annual sumptuous crops,
It gives such divine materials to men, and accepts such leavings from them at last."

This can be translated into the language of science in approximately the following way.

Modern technology draws into the production process enormous streams of materials: raw materials, fuel, water and air (including ventillated air). These truly gigantic streams are, however, at best processed into useless and, as a rule, harmful, toxic production waste, contaminating the sphere of man's vital activities, making it fruitless. The comparative share of the required and useful product received in modern industrial processes is negligible as compared with the share of production wastes.

The amount of raw materials extracted from the Earth, the streams of water and air drawn into the industrial process are so great that they can be compared with global geological processes. As the greater part of the raw material streams are in the final end transformed into wastes, the absolutely real threat arises of them ousting man. This process started long ago and is developing at such a rapid rate that it cannot but evoke anxiety and it must definitely be taken into account when forecasting technological progress.

* * *

Hence, the damnation of science and engineering which only yesterday were considered the cornucopia from which only the most diverse boons and wealth would rain. Anxiety for man's future on the planet has in recent years reached a high level, facilitated by the discussions in the press, statements made by

specialists and the publication of ever new facts on man's unreasonable attitude to his environment.

What is the solution?

The opinion of doctor Philip Handler, President of the US Academy of Sciences, is that: "we need more technology, not less; not less science, but more science." I am prepared to subscribe to his view.

We need a greater scientific approach to production; we should specify and in many aspects reconsider how to develop tomorrow's technology. We are in need of a greater consciousness of responsibility, and an analysis of everything which is known today.

For instance, it is well known that the problem of industrial wastes has a solution, not one, but several. These solutions today are no longer a scientific or technical riddle.

Let us examine how pollution is conducted, how and at what stage it can be decontaminated. We shall begin at the end, when the wastes are already in the air, water, and soil. The defensive forces of nature immediately take action. For instance, alien matter is devoured by microorganisms thus including it into the natural biological cycle, or, it is transformed without the participation of living creatures, under the influence of the air, water and solar light. Hence, whether one or other pollutants will or will not violate nature's equilibrium depends not only on their quantity but also to what degree they are "edible" to microbes, or capable of disintegrating under natural conditions. There were cases when the manufacture and use of one or other substances had to be given up as they, after having done their job, were too slow in decomposing under natural conditions. This concerns DDT and a number of other chlorine insecticides. The same holds true for sulphonal, at one time an extremely widely used detergent.

Until recently, man exerted all his energy to combat the destructive effects of natural factors. There is no need to look far for an example: metal corrosion causes a considerable loss to engineering in general. Enormous funds are spent in combating it. Today, however, we are simply surprised to learn to what degree corrosion is not an evil but a blessing.

Before the advent of what is known as the polymer age, the age of non-corrosive substances, hardly anyone was concerned with the disposal of, say, empty cans. Whether they were used as scrap metal or reduced to rust, i.e., to soluble iron compounds at dumps in no way reflected on nature. Later cans made from synthetic materials appeared on the scene and, naturally, they were also dumped. In the USA, for instance, 65,000 million such used plastic cans are dumped annually. In this case bacteria cannot help and the cans cannot decompose or disintegrate on their own!

This is why an astonishing trend has appeared in the research of new materials, especially that of packing materials. The target is new substances which, after fulfilling their direct purpose, would easily decompose. More so, the possibility of developing bacteria which can destroy the most "indigestible" polymers such, for instance, as polyethylene is being studied. Fundamentally, this is not considered impossible as genetic methods to some degree provide for directing the evolution of microorganisms in the required direction. (The following apprehension, however, immediately arises: shall we not be confronted in the near future with the problem of finding polymers which are unsuitable as food for the new "devastators of plastics"? After all bacteria are unable to judge what goods are, as yet, required by man and which he no longer needs.)

Thus, one of the fundamental ways of combating pollution is to use more fully the mechanisms provided by nature which process wastes and their inclusion in the general biological cycle. The sewage-water biological purification systems being used at present are essentially based on this system: the very same bacteria and the same most primitive organisms are used for the purpose, as a result of which the purification of rivers takes place. Especially favourable conditions are created for them, this resulting in a considerable increase in their efficiency.

What should be done, however, when the wastes are not merely an inert mass but something poisonous to everything animate and at the same time chemically stable? In such cases it is already impossible to rely on self-cleaning processes in the biosphere.

Here as well, in essence, there is no problem. The technology for cleaning discharged poisonous substances has already been perfected to such a degree that gases ejected into the atmosphere can in no way be distinguished from crystal clean mountain air, while sewage can be purified to such a degree that it will be cleaner than the water an industrial plant draws from a river or lake.

Incidentally, it is also in place to note that the content of harmful substances in fumes in many cases is of such a nature that no one knows whether they should be considered harmful or, just the opposite. Thus, for instance, the amount of silver in the wastes of certain production processes is 20 times greater than that in the Earth's crust, that of molybdenum—50 times more, while that of arsenic—250 times more! All these are valuable raw materials and can be extracted.

Not so long ago a factory which every month received more than one ton of chromium for plating

parts only used 200 kg of chromium efficiently, while some 900 kg were simply poured down the drain. Unfortunately such factories still exist. Annually thousands of tons of acids, alkalies and non-ferrous metals throughout the world are discharged with sewage. This is the output of entire chemical plants, metallurgical plants and mines. The impression gained is that part of these enterprises are merely producing sewage. This takes place at a time when we are compelled to mine underground for even poorer ores and spend enormous funds for this purpose. It can be said that wastes and ashes are already becoming a real source of expensive raw materials which are in short supply.

It stands to reason that the extraction of necessary substances from wastes is not easy, and in some cases it is much more difficult than obtaining them from natural minerals. The sewages from shops of a large plant are completely different in composition; on being mixed they dilute and thus, the concentration of valuable substances in most cases is negligible. In addition, it is no easy job even for chemical experts to separate the ingredients of this fantastic cocktail consisting of dozens and hundreds of substances.

Nevertheless, the perfection of purification is only a palliative, a temporary measure against a disease which threatens mankind.

I recall a short and expressive appraisal of the very essence of this problem which Academician Alexander Nesmeyanov gave several years ago. He was asked: "What is your opinion as far as the purification of water and air is concerned?" Nesmeyanov replied, "I have a negative attitude towards this problem," and added: "there is no need to purify air and water; it is much more important not to pollute them."

This is profoundly the case. I am convinced that the root-cause of the problem is not so much in insuf-

ficient purification of discharges as in the imperfection of production technology itself which makes such discharges possible. This imperfection is the result of the limited nature of our present-day technological thinking.

* * *

I maintain that there is no enterprise which, by using the achievements of science, could not manufacture more valuable goods and put out less waste. In their time the Americans were justly proud of the Chicago slaughterhouses where, literally speaking, everything was utilized, except the last cry of the animals. Today raw materials should be used in such a manner that even the "last cry"—harmful wastes—cannot remain. This confronts industry with an enormous and basically important new aim: to revise all the fundamentals of production which shaped in the course of centuries, all technological and machine-design solutions.

When designing a chemical factory we, as yet, of all the possible reactions select the one which produces the largest amount of the required product. Another, no less important, criterion has appeared: the reaction should not put out unrequired by-products which have to be discarded.

Factories without chimney-stacks—is how I visualize industry of tomorrow.

Such a new approach to technology, however, will also require great changes in the organization of industry, in its economics.

To cite an example: aluminium is obtained by the electrolysis of bauxites with the addition of cryolite—a substance which lowers the ore smelting temperature. During this process a large amount of fluorine is released. Fluorine is extremely poisonous, and power-

ful ventilation systems are installed in the shops to protect workers from poisoning. As a result, the fluorine content in the shops is within the permissible limits, but the area around such a factory is transformed into a lifeless desert. Fluorine, however, is a valuable raw material and chemists spend no small effort and funds to produce it.

It is not profitable to extract fluorine from the discharged gases of aluminium plants as its concentration is very low. This can be tackled from another angle—the electrolytic baths where fluorine is evolved could be hermetically sealed and fluorine could be obtained directly without any special expenditure. This preserves the environment and renders unnecessary the installation of intricate ventilation systems.

Nevertheless, this is not being done. Why?

Simply because aluminium plants are designed, built and operated by metallurgists for whom fluorine is a harmful gas. They are not interested in the fact that fluorine is also a raw material required by the chemical industry.

Industrial establishments of the year 2000 should be enterprises with the comprehensive utilization of raw materials, plants without any wastes. The motto of such industry should be the phrase already coined in the past century: "there is no dirt in chemistry; dirt is a chemical compound in an inappropriate place."

I again reaffirm that it is already possible today, taking into account the present level of science and technology, to build such enterprises. For instance, large thermal electric power plants which at present probably represent one of the greatest dangers as far as air pollution is concerned, could already today be designed as energy-and-chemical combines. Besides electric power, they could produce excellent cheap

building material (from ashes and slag—which at present are difficult to dispose of) and sulphuric acid (from sulphur dioxide which is at present discharged into the atmosphere polluting it on an unprecedented scale). Perhaps carbon dioxide which is discharged into the atmosphere in enormous quantities could be profitably used: say, by building hotbeds and green houses where carbon dioxide could be used as a gaseous fertilizer for boosting the vegetable crop. The same also holds true for the surplus heat.

In the new technology without chimney-stacks and wastes there will be no place for such thermal electric power plants which at a loss of a substantial part of the public wealth only supply society with electricity. They will be transformed into intricate comprehensive plants combining not only the generation of electricity with the manufacture of chemical products and building materials, but with farming as well. When this stage is reached, the problem of environment pollution by carbon dioxide, ashes and other thermal wastes will to a considerable degree be solved.

* * *

Perhaps some people assume that my ideas about technology without chimney-stacks and wastes are far from being immediately realized and have in mind only the far distant future.

This is not the case. Technology without wastes will be a practical problem on the agenda by the year 2000. Such ideas were also advanced in the past and what is more, they came true.

More than 30 years ago a modest-sized factory at Gorlovka, a Donbas town, mainly manufactured nitrogen fertilizers. Nevertheless, while producing fertilizers, aimed at improving the soil, the plant in its

work in no way enhanced soil fertility, as its production wastes poisoned the air and destroyed vegetation. In addition, with its sewage which was discharged, without thinking, into a nearby ravine, the factory lost annually 2,000 tons of sulphuric acid, 900 tons of nitric acid, 700 tons of ammonium nitrate and 1,000 tons of ammonium—almost the same amount as could be manufactured by a medium-sized factory.

The design of cleansing installations was undertaken but this proved to be a most expensive affair. It was then that the factory engineers thought of tackling the problem from another angle.

They questioned the very principle of purifying the wastes which, naturally, were directed into a single collector network, where the solutions of substances from the different shops mixed and diluted each other.

Tackling the individual links of this chain, the Gorlovka factory specialists reached solutions which were most paradoxical for the operation of chemical enterprises of that time: entire shops were in general isolated from the industrial sewerage system! The chemical substances, which in the past flowed through the drain causing a loss to the enterprise and harm to nature and to people, were now collected and an application for them found. Naturally, this was a complicated task, and it could appear to be a thankless job. It was necessary to construct appropriately equipped special drains, at times extremely poisonous, directly in the shops. The waste products had to be collected in quantities feasible for processing and methods had to be developed which would transform some substances into others that could be employed in the factory proper. The transformed products had to be used for manufacturing and placing on the market new products not formerly envisaged in the factory's plans and technological regime.

They were successful in this work. Within several years the Gorlovka nitrogen fertilizer factory was transformed into an enterprise operating with almost no harmful wastes and sewage. Only a few more steps were needed to complete the job when the war broke out and the work had to be curtailed. Nevertheless, this experience of the Gorlovka factory where, under the conditions of the far from perfect technology of the thirties, broadminded chemists advanced and solved that noble and profound task of state-wide importance, and I would even say, of importance for the whole of mankind, was not in vain.

Another example could be cited. This is the USSR uranium industry where from the very outset problems were placed and successfully solved concerning the comprehensive processing of low-content ores, the separation of chemical elements with similar physical and chemical properties, the problem of localizing radioactive wastes, closed water recycling.

The uranium industry, however, is not the only present-day example of wasteless technology or that proximating wasteless technology. The same also holds true for a number of enterprises mining non-ferrous and rare metals. A gold mining enterprise has operated for already a number of years in the Kyzyl-Kum desert, which has no equal both in labour productivity and in consideration for the environment. Generally speaking, sewage discharge is non-existent there.

Another example: Soviet chemists, machine builders and power engineers have developed a basically new method for the synthesis of nitric acid which excludes the discharge of poisonous nitric oxides. This means that time has come to completely put an end to what is known as "fox tail"—the brownish poisonous smoke of factories manufacturing millions of

tons of nitric fertilizers and simultaneously ruining vegetation.

All these solutions are already close at hand or will soon be accessible to all industrial enterprises. At any rate they will be fully at the disposal of technology by the year 2000. Hence, industry should in the near future develop precisely along these lines. Industry will build complex enterprises which will know no wastes, plants in which the streams of raw materials will in the course of the technological process be transformed only into products useful to man and harmless to the environment.

* * *

Those of us who will live to usher in the year 2000, our children and grandchildren, should be able to forget about poisonous fumes over factories (and perhaps about chimney-stacks as well) and about polluted air in cities. They should know only clean lakes and rivers, only a living ocean.

To achieve this, our wishes are not enough and the science and engineering possibilities are insufficient.

It is becoming ever more obvious that the problem of clean water and clean air is no longer a technical one: it has become a social problem. There is a serious and profound reason in placing this question in, perhaps, a somewhat acute and sharp form. It would be simply foolish not to realize that mankind's future depends on how seriously every person is aware of his responsibility, both to our contemporaries and descendants. Every person, from an operator at a chemical plant who has no right to succumb to the temptation of opening up a sewage disposal valve to get rid of spilt acid and to the director or even a member of the government. The whole of mankind is responsible for the state of the biosphere.

It stands to reason that it is insufficient to appeal only to a sense of duty, to a sense of responsibility. At all levels in any country there are always more than enough irresponsible people. Hence, it is extremely important to substantiate conviction with compulsion, including legislative measures. An old principle of Roman law says, "where there's no law there's no crime". When a law exists and well-known actions can be taken in case of its violation, irresponsible persons think twice.

Unfortunately, few countries have laws prohibiting biosphere pollution. Such laws are in force in the USSR. This does not mean that the problem is fully solved here. Nevertheless, we have already adopted several laws aimed at enhancing nature conservation and improving the utilization of natural resources.

As a consequence of new laws, a gradual change in social psychology on the realization of "what is allowed and what is prohibited" in our relations with the biosphere will occur.

I would like to cite a somewhat ridiculous but appropriate argument.

The problem as to whether strict discipline should be demanded from pedestrians in crossing city streets was discussed in one of countries. The stipulation that a street should be crossed only on a green light, according to some persons, was not in accord with the national character of that country's inhabitants. Then a resolute step was taken. Fines were introduced or to be more exact the already existing fines were increased 20-fold.

A short time passed and the people in that country stopped crossing streets against red lights. It seems to me that their actions in this case were not to the detriment of their national character.

Laws based on a profound understanding of our dependence on the biosphere would also help solve the problem of conducting production as a complex whole, without wastes.

One of the aspects of such a comprehensive approach is that the design of new plants should be carried out by "disinterested" organizations. This is a complicated matter as designs should be made by the best specialists in that particular line. At the same time the design of plants should become completely independent of departmental interests. Such should be the aim, as this work is of general state and public benefit in which concern for the co-existence of man and the biosphere is definitely taken into account.

* * *

I should like to raise in this respect an extremely important point as far as socialist economics is concerned.

Fluorine is released into the air during the electrolysis of aluminium because its accumulation is unprofitable. But this is only unprofitable for an aluminium smelting plant!

The blast-furnace and open-hearth slag of iron and steel plants is by far not always used efficiently. This is unprofitable, but only for metallurgists. It would, however, be useful to consider what would be the result if the slag is used for paving streets or for construction work.

Sulphur dioxide traps are, in the final analysis, not installed in electric power plants because this is not profitable. But for whom? Probably this is unprofitable for power engineers, however, it is still necessary to estimate whether this is profitable or not to the state. None doubts that generation of electricity

entails expenditure. For instance, expenditure is involved in the production of steam for the turbines of thermal plants. Is there any sense in such a statement that "steam production is unprofitable for the generation of electricity?" One may answer that the statement is absurd as without steam a turbine would not rotate.

This leads to the point: without purification there will be no life on Earth. Hence, it would be logical to consider that the purification problem is just as important as the production of steam for turbines. Both these assertions should be equally categoric.

Profitable or not, economical or not, this is the important question in socialist economics. Hence, economists are confronted with the great task: to determine the sum profitability of this or that line of production. It is necessary to integrate all the profit of the given enterprise and industry, and determine all the damage caused to society by the incomplete utilization of raw materials lost in the wastes, damage caused by wastes in poisoning the air, in causing corrosion, crop losses, extermination of fish and fowl and, finally, the damage resulting from the harm caused to the health of people.

When the damage caused to society by a branch of production is greater than the profit, then such a branch of production in its present form has no right to exist!

Unfortunately, we as yet can almost never present precisely the correlation between benefit and harm caused to nature by our activities, especially in the language of economics. The customary concepts of profitability and economic effectiveness do not include all the main and side results of economic activity. What is taken into account is only the apparent benefit received by society from the manufacture of one

or another product while the indirect harm caused remains in the background. In the end, water and air pollution, the squandering of natural resources—all this, sooner or later, will turn against us. One can visualize such a state of affairs when we shall have to exert ten times more effort than at present to compensate the damage caused to nature.

These considerations, if not realized and if our attitude towards environmental pollution is not changed basically, may be of decisive importance. After all a great deal of work has to be spent in order to establish whether a substance is harmful or not, to what degree and for whom it is harmful or harmless and in what quantities. This requires the work of a large collective of scientists. Several years will be needed to authoritatively establish to what degree only one substance under examination is harmful, what is its maximum permissible concentration in the air, water, or soil!

Besides, who is in a position to decide with certainty what maximum concentrations are permissible and for whom they should be considered: for man or, for instance, for the green forest? All biological chains in nature are intricately interlinked; man is frequently even more enduring than his friends in nature.

Nevertheless, after proving the dangerous or comparatively harmless nature of only one substance, one cannot be sure that this has been done sufficiently well and completely. This is the case as every known product or substance, as a rule, has dozens, and perhaps, hundreds of by-products which quite often contain unknown mixtures of unstudied compounds. In addition, nature in a way is a gigantic reaction vessel where numerous and most intricate chemical reactions continuously take place. As yet we by far do not know

about many of them. Thus, no one can as yet correctly appraise the entire number of chemical compounds and their quality which befall man and everything animate in nature.

In many cases we cannot correctly predict the remote consequences of the effect of what would seem to be quite harmless substances. Indeed, besides the directly toxic influences, we know of teratogenic (causing malformation), mutagenous and others affecting distant posterity.

Thus, society lacks and, probably, will never have sufficient forces and opportunities to substantially determine the maximum permissible concentration of all these substances in our environment and provide everything animate with complete safety against the influence of each of these substances. To cope absolutely with this great task is beyond mankind.

Time is running short. In the course of the historical period in which we are living, the indices of environmental pollution increase according to the exponential law. This is clearly in accord with the increase in the indices of industrial production. Rains are already being registered in the North-West of the United States with a 2.1 pH acidity (due to solution of sulphur dioxide in rain water). Such rain has a greater acidity than vinegar! Without preventive measures being taken, such rains will also occur in other districts. Our Earth is not so big and there will be no place to take cover from them. An acidic rain is unpleasant; but toxic, teratogenic or mutagenous rains are more "unpleasant".

There is only one solution: nothing should be dumped. Industry and in general all factories should be reorganized in such a way that their activities do not violate the equilibrium in nature.

This, however, requires time. Time is also needed for this point of view to prevail; for economics, proper, to change; for the ideas of this science to undergo change as well. I am confident that a new science will appear in the near future: bioeconomics—a science combining economics proper and ecology. (Perhaps it will be known as ecological economics or will have some other name, but the point is not in the name.) In the very near future we shall start counting "from both ends", as P. Oldak, a Siberian economist, puts it.

Many economists are convinced that it is necessary to speedly include the cost of natural resources in economic estimates. Academician N. Fedorenko, Director of the Central Economical-Mathematical Institute, advances the following preliminary data in the expert appraisal of the Soviet Union's natural wealth (these data were published in 1972): agricultural land—180,000-270,000 million roubles, timber resources—45,000-50,000 million roubles, mineral resources—70,000-100,000 million roubles. This totals 295,000-420,000 million roubles, which can be compared with the present value of all fixed production assets (buildings, structures, machines, roads, etc.) of the Soviet Union's national economy—approximately 460,000 million roubles.

Soviet economists have no intention of proposing to immediately assess in terms of money, literally speaking, everything in nature. "How will you assess the Gulf Stream?"—is an argument advanced by the opponents of an economic appraisal of natural resources. Although they consider this a formidable argument, it is not as weighty as it may seem: at present it is too early to "assess the Gulf Stream". It is, nevertheless absolutely unknown whether this objection will be simply naive tomorrow or the day after tomorrow,

when the Gulf Stream will indeed be needed by the people.

When speaking about the future of bioeconomics, it seems to me that if today we have as yet no need to ponder over the Gulf Stream, there is reason to think about the future of another unique creation of the hydrosphere—that of Lake Baikal. The more so as the fate of Baikal directly concerns the near future which we are duty bound to foresee scientifically.

It would be absolutely impossible (and in addition there is no need for this) to expound in detail in this article the history of the construction of two plants at Baikal (one of them already operates), to deal with the polemic conducted in the Soviet press concerning this construction, with the great state efforts and the persistent work aimed at preventing the industrial wastes of these plants from spoiling the remarkably clean Baikal waters.

There can be no doubt that everything possible will be done that the Baikal waters remain clean (incidentally, the cost of these efforts will be enormous: I do not know whether the goods manufactured by the Baikal cellulose plant and those of the Selengin cellulose and cardboard plant at present under construction, after all the expenditure on the purification of their sewage will justify the funds invested). But another point needs to be stressed: the very approach to this problem. Situations similar to that of the Baikal problem will have to be tackled in the future many times.

Academician P. Kapitsa recently wrote in the newspaper *Pravda*: "Industry needs fresh water. Baikal has a colossal amount of such water. It is of enormous value. The lake is even more valuable as it presents a gigantic powerful biofilter producing clean water.

For us Baikal's industrial importance is that the

lake serves as a powerful water purifier and we should preserve this ability. Hence, the slogan 'Hands Off Baikal' is wrong. This unique lake can and should be used, but in such a way as not to violate its life or spoil its purity. Chemists are confronted with the task of elaborating technological processes which will make the wastes pure to a standard that satisfies biologists, i.e., the wastes could be processed by Lake Baikal".

I also consider that many of the above points are irrefutable and correct. It is my opinion, however, that the data on the lake's enormous value (incidentally, even today it is hardly possible to estimate this with sufficient accuracy) and its unique properties can serve for drawing other conclusions as well.

Indeed, Lake Baikal has a colossal amount of fresh water, some 23,000 cubic kilometres. This is approximately 20 per cent of the Earth's surface resources. This is a gigantic biofilter continuously producing clean water. Indeed, the importance of Lake Baikal is that it serves as a powerful water purifier.

This is, however, not all! Why is it necessary to directly exploit this great reservoir and not be satisfied with an exceptionally powerful water-supply line which, it would seem, nature specially built—the Angara river which flows from Lake Baikal?

Yes, the lake is a powerful water purifier, but does it really insufficiently purify the water? Are there calculations which show that it is expedient to build so many plants in this area that the water from the Angara would not be sufficient to supply them with water?

And one more point. I hope that there will be an opportunity to correctly assess the state of affairs in the language of figures, data which will show whether it is expedient to attempt to burden Lake Baikal with

industry. I am confindent that the figures will simply declare "No!" Confidence, however, as yet does not replace computations. Would it not be better to wait until the problem can be solved with sufficient reliability? Until the estimates of the bio-economic programme clearly reply to the question: how should we act in a more advantageous manner? Is it more expedient for society to build up industry "on clean water" in this region or to designate it only for holiday-making and tourism and, what is the main point, to preserve clean water? Or perhaps combine both objectives?

There is also another argument based on observations conducted in the course of many years. Those who support the idea of "single", "individual" industrial enterprises being built in areas with unique natural conditions simply engage in wishful thinking. Social-economic processes in present-day society are of such a nature that industrial enterprises inevitably "multiply". This is no accident and not the result of somebody's caprice or of arbitrary decisions. This is a natural course of development: industrial establishments do not exist in solitary isolation.

* * *

Perhaps nothing in the world shows with such great clarity the need for the unity of people on Earth as the impending crisis in our relations with the biosphere. There can be no doubt whatsoever that every nation, every state is above all concerned about its natural resources, its territory, its waters and the ocean of air over its land.

Today this is, however, insufficient. Mankind's very existence in the biosphere is a global problem and it is simply impossible to solve it within the con-

fines of the borders determined on the map of the world. There are numerous examples showing that this is not only a point for discussion but already a day-to-day reality. To cite one such example.

It was discovered in Norway that the acidity of water had increased in the lakes in the country's mountainous areas where industrial wastes are excluded. It appeared that the reason for this was most prosaic. The water in the mountain lakes became acidified by that same sulphur dioxide carried by rain and snow. Clouds saturated with the smoke of factories and electric power plants in Europe's industrial areas carry drops of sulphuric acid over enormous distances, over all and any borders.

It is now absolutely obvious that the efforts of different states must be combined, irrespective of their social and political systems. This approach is precisely characteristic of the Agreement on Cooperation in the Field of Environmental Protection concluded in 1972 between the Soviet Union and the United States of America. It proceeds from the fact (as proclaimed by the Agreement) that "the economic and social development for the benefit of future generations requires the protection and enhancement of the environment today". This approach is precisely characteristic of that major international document of our time, the Final Act of the Conference on Security and Cooperation in Europe. It declares the common aims and the joint actions of states in this sphere, one of the most important tasks of our continent.

* * *

We shall strive that both parts of our world—its biosphere which is primordial and the technosphere which man has created—jointly get along and supple-

ment each other. They have to be combined and their coexistence must without fail be peaceful: in case of a catastrophe the losses of both sides would be so frightening that no one can tell whether anything would remain intact (whether it would be the biosphere or civilization is already of no special importance as the latter is, nevertheless, part of the former).

Scientific researches, economic substantiations, engineering estimates and the unanimity of biologists and technologists are insufficient to speedily achieve that peaceful coexistence within the period we have in mind (it is not such a lengthy period). It becomes obvious that global ecology must be considered.

This requires an adequate education of the whole of mankind. Every future generation must know the laws of the biosphere-civilization coexistence and must be aware of the "biotechnosphere". Ecology, the science of the mutual relations between living organisms and their environment, should become the corner-stone of modern science. Such is the opinion of P. Oldak whom I have already quoted. The time has come to form an "ecological world outlook". We have, probably, already embarked on this task, with books, magazines and newspapers playing the leading role. Up till now ecology studied the existing equilibrium in nature which had shaped in the course of evolution. Ecology now is a practical science and it will have to solve many diverse practical problems.

The road to such solutions will neither be simple nor easy as many countries, and in the first place the most industrially developed ones, will have to launch special state programmes on the restoration of the damage caused to the biosphere. For instance, it is known that the USA will have to spend, according to some estimates, a truly astronomical sum

of 500,000 million dollars for the purification of already polluted water sources. It is not excluded that the realization of these national and international programmes will require revision of other expenditures and other projects.

* * *

As far as international cooperation in the protection of nature is concerned the first steps are now only being made. Nevertheless, it is high time to think about the road to be selected. Just as in the case of social development, two basic paths are possible here. Several years ago Professor George Wald, a prominent American biochemist, wrote that the choice is the one between biology and technology.

The biological path means evolution in the course of which all possible variants of development are tested with the unsuccessful ones dying out. The technological path implies a precise formulation of aims and the quest for the optimal method for their attainment. Professor Wald prefers the first method.

My opinion is that one cannot agree with this when we have in mind the existence of mankind as a biological species. One cannot agree with this as at each fork of the road of natural evolution, one path leads to doom. This is the price which we would pay for a mistake in the choice of road. Karl Marx long ago realized that when culture develops spontaneously, and is not directed consciously, it leaves a desert in its wake. Today there can be no doubt that, having clearly realized that the aim is to preserve our planet, we are obliged to establish, as far as this is within our power, the correct path to achieve this aim.

* * *

I fully realize that there are many facts which subject to no easy test our optimism as regards the future of our Earth. Several years ago the press published a composition written by a British schoolgirl in Southampton. Here are several lines: "Today is a black sultry day. It hardly differs from other such days. My mother once told me that the sky was blue, but one can only believe what one sees. For me the sky is always black or yellow, I like it that way, it is more natural.

In the museum one can see stuffed birds. People say that they once flew, but I find it hard to believe; they seem too clumsy. Perhaps, they flew very slowly. They are not like aeroplanes and are completely useless. Planes serve a definite purpose; but who needs birds?

My grandmother loved them. She told me how they sang. She also liked flowers, but I like the smell of machine oil. It is fresher. In addition, machine oil is useful. It keeps life moving."

There are quite a number of reasons for such tragic sarcasm beyond one's age. It is, however, within our power that childrens' fantasy remains the way we are accustomed to see it: bright and cheerful.

Another newspaper statement: People in the cities should always see the sky, the stars and the sun. These are the words of the mayor of Moscow. In the reconstruction plans of cities, in the designs of new construction projects, Soviet town-planners envisage industrial enterprises being built beyond residential districts, the traffic being transferred underground. Designs are being elaborated for ventilating Moscow's streets, so that people can breathe freely in the city. Plans have already been drawn up according to which

parks and gardens will replace many streets in Moscow, approximately 20 per cent of the entire territory of the Soviet capital.

Perhaps for the implementation of this task education will be a no less important means than economics and technology. Education in the family, in the school, at work and in society. The moulding of an ecological world outlook, starting at the very beginning, from kindergarten to university. This is a lengthy process and far from easy. Nevertheless, I foretell that the generation which will be coming into the world within a quarter of a century, in the year 2000, will consider it absolutely impossible to destroy forests, poison air and pollute water.

* * *

A problem of unprecedented magnitude confronts man, the supreme creation of nature. This task is incomparable with anything which in the past had to be tackled on Earth: it is a basically new task. These words can be repeated a thousand times. Even people with great foresight for a long time failed to notice this problem. When thinking what I should stress in this article, I wanted to know how Ivan Yefremov, a science fiction author and scientist, visualized our future coexistence with nature.

In his book *Andromeda Nebula*, describing centuries yet to come, where literally all the problems of future society would seem to be mentioned, I found no answer to my question. "Work is happiness, as well as an incessant struggle (!) against nature"—I failed to find anything else in the novel. Only much later did I. Yefremov points out that one of the most important features of the future is not only the blossoming of biotechnology, not only the adaptation of a highly developed civilization to animate nature, but

the hopeless blind alley, the doom of the animate world on the planet Tormans, resulting from the refusal to understand the need for the coexistence of man with nature.

Who is duty bound that everyone be fired with concern for our future on the Earth? How should the next generation be brought up, so that it will cause no harm to the home in which we live? This, most certainly, is the duty of the kind and sensible printed word.

If this appeal in the press and in books has resulted in it becoming "fashionable" to discuss the dangers threatening the biosphere, then I am fully in favour of such a fashion. Let it remain in vogue until there be a clean sky over the Earth.

TO THE READER

Mir Publishers welcome your comments on the content, translation, and design of the book.

We would also be pleased to receive any suggestions you care to make about our future publications.

Our address is:

USSR, 129820, Moscow, I-110, GSP, Pervy Rizhsky Pereulok, 2, Mir Publishers

Printed in the Union of Soviet Socialist Republics